INDUCTIVE PHYSICAL SCIENCE

BAILEY

Experimental Science Series

I.

INDUCTIVE ELEMENTARY PHYSICAL SCIENCE

WITH 5501

INEXPENSIVE APPARATUS, AND WITHOUT LABORATORY EQUIPMENT

BY

F. H. BAILEY, A.M.

AUTHOR OF "PRIMARY PHENOMENAL ASTRONOMY," INVENTOR OF THE "ASTRAL LANTERN, OR PANORAMA OF THE HEAVENS," THE "COSMOSPHERE," "100 IN 1 PHYSICAL SCIENCE APPARATUS," ETC.

BOSTON, U.S.A.
D. C. HEATH & CO., PUBLISHERS
1897

Typography by C. J. Peters & Son, Boston.
Presswork by Rockwell & Churchill.

PREFACE.

THE course in Elementary Physical Science, of which these pages form the first instalment, is the outgrowth of various experiments made first in the public schools of Michigan, later in Dr. Felix Adler's Workingmen's School in New York City, and finally, during the past four years, in the private school of Mrs. Quincy A. Shaw in Boston, — a school founded by Mrs. Shaw, the daughter of the great naturalist, Professor Louis Agassiz, for the purpose of developing methods of nature study that will secure to the young student the best preparation for holding through life intimate converse with nature.

The endless source of happiness which this gives is a heritage that Mrs. Shaw has believed will come always to all students who are introduced to the study of the earth by the natural method. The author's educational views were so fully in accord with her own, that she gave him perfect liberty in laying out the work in the Physical Science branches of nature study for pupils from twelve to eighteen years of age. The results reached have been such that many of the best educators of Boston and vicinity have recommended and urged that the course be given a wider field of usefulness.

While this work has been largely the result of class-room experiment, indebtedness is freely acknowledged to

various sources, especially to the excellent little manual on "Home-made Apparatus," by Professor John F. Woodhull, of the New York Teachers' College.

For any testimony that may be wished in regard to the merit of the course, the following are referred to: Mrs. Quincy A. Shaw, Boston, Mass.; E. Bentley Young, Master of the Prince School, Boston; Charles F. King, Master of the Dearborn School, Boston; W. A. Mowry, President of Martha's Vineyard Summer School; S. T. Dutton, Superintendent of Brookline Schools; Larkin Dunton, Head Master of Boston Normal School; A. E. Winship, Editor of *The Journal of Education;* and Frank A. Hill, Secretary of Massachusetts Board of Education.

F. H. B.

6 Marlboro Street, Boston, Mass.
January, 1895.

CONTENTS.

	PAGE
Preface	iii
To the Teacher concerning:—	
The Course	vii
Apparatus, in General	xi
Apparatus, Home-made	xiii
Apparatus, provided by the Author	xvii
Additional Appliances	xviii
The Laboratory	xx
Preface to Second Edition	xxiii
Auxiliary Work	xxiv
Quantitative Work	xxvi
Methods of conducting the Work	xxvi
Letter from Principal E. B. Young	xxix
Letter from Author to Pupil	1
Study of Apparatus, illustrated	5
Directions for adjusting "100 in 1"	10
Water Experiments	13
Air Experiments	30
Quantitative Air Experiments	52
Buoyancy Experiments	61
Specific Gravity Experiments	64
Density Experiments	68
Volume by weighing	70
Auxiliary Work	71
Appendix	100
"100 in 1 Physical Science Apparatus"	106

TO THE TEACHER.

No previous knowledge of physics is absolutely necessary; but a clear conception of the *object* aimed at is imperative, in order that the work may be done in a scientific manner, and the highest success attained. That object is not primarily to give the pupil a few physical facts out of the great abundance of truth, a few essentials of which is all that is possible in any course, but to cultivate his powers of observation and independent thought. Every young child possesses these powers, and is eager to use them; but a system exclusively of book-education tends to destroy them. Some one has truthfully said, "No injustice would be done to a teacher if his skill and the educative value of his lessons were measured by his success in making children reason out conclusions from observed or stated facts;" and we may add that for the best discipline those facts should be observed, not stated. *That* education is of the most value in every walk of life which not only enables its possessor to reason correctly upon facts possessed, but which gives him the power of keen and accurate observation by means of which to collect the facts for himself. Seeing is not so simple an act as many suppose. Every scientist knows that it is one thing to turn the eyes towards an object, but quite another thing to see what is there. Every one's observational powers need cultivating, and

"Observation Lessons" are of value for this purpose, but doubly valuable when so arranged as to become an incentive to logical reasoning.

In planning this course these two objects have been kept in view, and they should be continually before the teacher in charge. If the course is properly taught, pupils who have been in the habit of learning, or trying to learn, without independent thought, find that it is impossible to do so in this work. They are compelled to use their eyes in collecting facts, to put these facts together, and to draw conclusions from them. These processes at their command, they are then prepared for the great school of life; but without having acquired these processes, no amount of accumulated facts are of much value. Teachers who have never tried this method will be astonished at the ease with which children adopt it. At first, if their previous instruction has been entirely by the memory method, this one seems to fail completely. The pupils can use neither hands, eyes, nor minds. They cannot experiment successfully, nor see more than a small part of what happens when the experiment is done, to say nothing of thinking out what it all means. But I have not yet had a pupil whose habit of leaning upon book or teacher was so strong that it did not give way, within a brief space of time, and let some degree of self-activity show itself. In training the pupil to self-reliance, it is at the very beginning that the skilful teacher has the opportunity of doing his best work. I have tried several methods: one extreme is to assist the pupils in every step at the beginning, and wean them gradually; the other, to throw them entirely upon their own resources from the very beginning. Of the two extreme

methods the latter is the better, provided the pupil can be prevented from becoming discouraged before he gets a start.

The particular method in which you conduct your class will, of course, depend upon circumstances. Only general directions can be given. Though you have no *teaching* to do, that being done by Nature, the best of all teachers, nevertheless you should *teach* (if we may use the paradox) by the most successful method — that of example. *Be* a student of nature with your class, and *acknowledge* yourself such. Have a set of the apparatus, try the experiments, and write your inferences just as your pupils do, either at the same time or previously. You will become interested in the work, and that interest will spread to every pupil. That, at least, has been my experience. Children are imitative; and when they see you doing and enjoying interesting experiments, they will wish to do them also. At the same time you can easily appeal to another element which is still stronger in most children — that of emulation; not an unworthy incentive to appeal to, especially if it is done with skill. They will compare their inferences one with another. Get them to compare with yours. You should also examine their written work, and commend all of it that shows independent effort. Frequently you can commend pupils for their discoveries, at the same time that you criticise their statements of facts. Always commend when you can, and criticise with moderation.

There is no better way to become acquainted with your pupils, and no better opportunity for doing individual work. It is sometimes claimed that it is impossible to

individualize with the pupils in our public schools when the classes are large; but by this method it becomes comparatively easy. After school you have in your possession the notes written during experiment hour; and through them you rapidly become acquainted with your pupils, and see just how you can best help them. Frequently they need no help, with the exception of some brief marks agreed upon to indicate the mistakes you wish them to correct. Some pupils may need a word of encouragement or direction; and this is usually more valuable if given in writing, though sometimes it is better to speak to them privately. Seldom speak to a pupil in class, unless it is in a whisper; for the class-hour should be a silent one on the part of teacher as well as pupils. If you would have it quiet, keep quiet yourself.

For suggestion for correcting books or papers, see note to "Author's Letter to Pupils." This method of studying science furnishes one of the best opportunities for discipline in English composition; for pupils have something to write about, consequently essay-writing becomes easy and pleasurable, and pupils form the invaluable habit of writing upon subjects about which they know something, and of expressing their own thoughts and discoveries. In fact, the many incidental benefits derived from the course are of more value than even the physical knowledge gained. Moreover, aside from the particular physical facts that the pupil discovers, there are general ones of much greater value, which can neither be understood nor appreciated unless reached through the individual experimental method; such as the fact that the answers obtained from nature depend upon the questioner; that they approach the truth

in proportion as the question is properly put, and the answer carefully read; the immutability of the operation of nature — the fact that exactly the same causes always produce exactly the same results; the fact that there is no such thing as chance, every effect having its cause; the fact that the so-called "natural laws" are simply our explanation of nature's uniform operations. By this method of study, as one of our critics has put it, "the pupil comes to see things as they are, and not as he thinks they ought to be."

APPARATUS.

Of no less importance than the outline of the course in physics is the apparatus with which the experiments are performed. To meet the wants of grammar schools, the apparatus should be neither extensive nor expensive, but it should be sufficient and of an interesting character. In order to obtain from it the best discipline, not only should the apparatus itself be carefully considered, but the means by which it is provided. Theoretically, the plan for using home-made apparatus is the best; but this plan has usually failed to be very satisfactory in practice, because of the crudeness of the method by which it was attempted. Pupils will do much in the line of making their own apparatus after they have become interested in the work, but generally not at first.

We have found it the best plan to provide the pupil at the beginning with simple apparatus for trying interesting experiments; then to lead him, after his interest in experimental science is aroused, to increase his stock by such pieces as he can easily make for himself. No matter

how simple it is, he takes more interest in experimenting with apparatus provided for the purpose, especially if it is of his own make, than in using articles not set apart or especially fitted up for his purpose.

Interest the pupil in experimental science; then provide him with files and a little glass and rubber tubing, and he will find his own cans and bottles, and make his own apparatus. We have seen this method produce such excellent results that we cannot too earnestly recommend it.

In order, however, to adapt this work to the widest possible range of conditions, it is published in two parts — the "Elementary Physical Science," and the "Auxiliary Work." The first part is complete in that it brings out every essential principle of the subjects treated. This, together with the apparatus which we provide, is adapted to such schools as, for any reason, cannot adopt the home-made apparatus plan.

The "Auxiliary Work" consists of clearly illustrated directions for making extra apparatus for experiments which will be found useful, either to bring out the principle sought in a different and more striking manner, or to furnish interesting applications of laws already learned.

To make applications is as essential in the study of physics as in arithmetic; and for that purpose a variety of experiments is better, and far more interesting to the pupil, than a number of problems. In a very few cases (two or three only, in this first course), where applications by experiment are not practical, problems are given.

Another benefit afforded by the "Auxiliary Work" is that it furnishes an easy entering wedge for manual-training work, the value of which is now conceded by our best

educators. Whenever it is possible, pupils should be permitted, or even required, to make their own apparatus. Except the drilling of holes in glass bottles, it can be readily done — even this is not so difficult as at first it seems; it has been repeatedly done by the younger pupils of the author's classes. Not only does the pupil take more interest in performing the experiments with apparatus of his own making, but he is at the same time training the hands as well as the mind. Moreover, there is a fascination in the endeavor to acquire precision in either wood or in metal working — there is an especial fascination in the manipulation of glass designed for apparatus. Pupils have willingly devoted most of their leisure time to such work — with the broken ends of three-cornered files, drilling holes in thick glass bottles — making them true with rat-tail files — bending and blowing glass tubing — in fact, themselves making, from beginning to end, apparatus capable of use for fairly precise quantitative results. They did not always exactly reproduce things they had seen, but exercised their inventive powers, and occasionally produced something new. Thus these young pupils became not only *discoverers* in the field of physics, but *genuine inventors;* and they obtained a better education by such efforts than book study alone could ever have given them.

DIRECTIONS FOR OBTAINING MATERIAL AND MAKING APPARATUS.

Illustrated instructions in glass-working that will be useful to all, whether provided with the regular apparatus or not, are given, under the heading of "Auxiliary

Work;" but a few preliminary directions will be especially helpful to those who make *all* their own apparatus. The body of the "100 in 1" apparatus may be made of almost any wide-mouthed bottle. The most difficult part of the work lies in making the holes. I know of but one way that is generally practicable for the student, and that is the one mentioned above as used by my own pupils. Holes may be made with a hard steel drill held in a carpenter's brace; but the drill requires frequent sharpening, and the novice will break more bottles than when using a broken file held in the hand. In some localities machinists can be found who will drill them. It is claimed that glass is more easily drilled when wet with turpentine; but I find that water does just as well either with file or drill, and I have frequently made the holes with files without using any liquid. If a file is used (and an old worn-out one is just as good as any), when the corners become dull lay the end on a piece of iron, and break off the end with a hammer. After a little practice a very small bit at a time can be broken off, and so the file can be used for drilling many holes. Hold the bottle firmly, and be satisfied with slow progress, especially when the hole is nearly through.

It is advisable to obtain the rubber tubing first, then to make the holes just the size for it to fit snugly. The tubing, obtained from druggists, school-supply, or rubber dealers, should be of the best quality. Nothing is more unsatisfactory than poor rubber for the short pieces that unite glass tubes and bottle. For that purpose even the best quality, if very thin-walled, does not work well. Each set of apparatus requires about three feet; and, if

the best is obtained, the short pieces can be cut from the long one, and, if lost, easily replaced. One inch, however, of the best quality and thickness, together with three feet of cheaper tubing (if it is not the poor, half-clay stuff), will answer very well. The soft glass tubing should be of medium thickness; for, if thin, it breaks too easily for pupils' use. A good quality is furnished by school-supply dealers, at prices from fifty to seventy-five cents per pound. The glass tubing should be a very little larger than the hole in the rubber, so that it will make the connection with the bottle not only water- but air-tight, even under the pressure of two or three atmospheres. As the glass tubing is sure to vary somewhat in size, select carefully that which fits best for pieces that are used in bottle holes. Other sizes may be used for Pressure Gage, Equal Armed Siphon, Siphon Fountain, etc.; even the pieces to be used in the stopper may vary more than those in bottle holes. The latter should not vary a thirty-second of an inch in order to work well. The variation may be greater, however, with thick than with thin rubber connectors or packing.

Corks, if of the best quality, may be used quite successfully for most of the experiments, though rubber stoppers are *much* better. If corks are used, soften by rolling them on the floor with the foot, using considerable pressure, after which make the holes with a rat-tail file, if not provided with regular cork-borers. If rubber stoppers are used, get the best; though the difference in price of rubber stoppers is considerable, it is not comparable with the difference in satisfaction afforded, and the best will last much longer without becoming hard. We have

been using some for four years that are yet excellent; and others that were very good at first are now so hard as to be utterly worthless. The difference in the length of wear of rubber tubing is even greater than that of stoppers. We have four-holed stoppers of the best shape and material made on purpose for the work; but the best quality with two holes, always to be found on the market, do just as well for nearly every experiment, provided they fit the bottles perfectly. They should enter but a very short distance, and should not flare enough to prevent being crowded in nearly their entire length. Most stoppers flare too much to work well in some experiments, unless the neck of the bottle flares nearly as much. The holes should admit the glass tubes easily when the stopper is not inserted in the bottle, and is wet. For these reasons, stoppers and rubber tubing should first be selected, then glass tubing obtained, and the holes in the bottle made to correspond. Stoppers of the same make and number are of the same size, but not so are the mouths of bottles of the same "batch." They vary more than most dealers will admit. Hence the stopper and the bottle should be seen to fit perfectly before labor is expended in hole-making.

If you collect pickle or similar bottles (which can usually be done cheaper than buying from dealers), and order stoppers and tubing by mail, specify that the outside diameter of the glass tubing must be the same as that of the hole in stopper, and the diameter of hole in rubber tubing a *very* little less.

We give below the price and number of the best two-holed stoppers furnished by the Franklin Educational

Company of Boston, for the smallest-mouthed bottles that are convenient both to obtain and to use.

No. 10, price 45 cents, is a trifle too large, and No. 9 is not large enough, for a $1\frac{1}{4}$-inch hole, but just right for sizes between $1\frac{1}{4}$ and $1\frac{3}{8}$ inches. From $1\frac{3}{8}$ to $1\frac{7}{16}$, No. 11, price 50 cents. From $1\frac{1}{2}$ to $1\frac{5}{8}$, No. 12, price 55 cents. No. 12 is exactly $1\frac{1}{2}$ inches diameter at the smaller end, hence will not work well for all experiments in a $1\frac{1}{2}$-inch mouth, but will for one a trifle more or less than $1\frac{5}{8}$. These stoppers have holes the same size, namely, $\frac{1}{4}$ inch diameter; No. 9 has smaller holes. Price of an *excellent* rubber tubing to fit $\frac{1}{4}$-inch glass is 8 cents per foot; of the very best (the same we use and furnish), 10 cents. The same size tubing can be bought for 4 cents, being, of course, a much inferior quality.

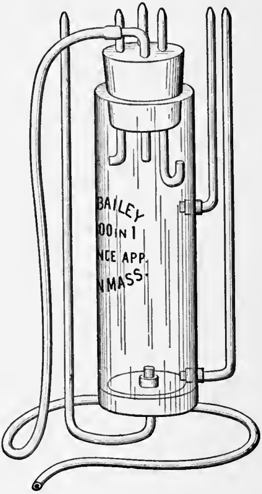


Fig. 1.

THE "100 IN 1" PHYSICAL SCIENCE APPARATUS.

In order to meet the wants of such as cannot make all their apparatus, we furnish sets at the lowest price consistent with the best material and workmanship. Instead of bottles with drilled holes, we have devised a

glass cylinder, the "Apparatus," which is much better. This is shown in the cut, together with the largest number of attachments used for any one experiment. This cylinder is made of clear pressed glass; consequently mouth and holes do not vary in size, the latter, for the easier admittance of connectors, flare slightly. It is $5\frac{1}{4}$ inches tall (more than $2\frac{1}{2}$ times that of the cut), $1\frac{5}{8}$ inches in diameter, with a thickness of $\frac{1}{8}$ inch at the top, which increases regularly to $\frac{1}{4}$ inch at the bottom. The thickness of the bottom (the only thing which can vary, and slight variation there does not affect its utility) is from $\frac{1}{4}$ to $\frac{3}{8}$ of an inch. It is not easily broken, usually sustaining a fall from table to floor unharmed, though not always, depending probably upon the way it happens to strike.

ADDITIONAL APPLIANCES FOR EACH PUPIL OR SCHOOL.

A few articles easily obtained, differing somewhat according to circumstances, are needed, together with the regular "100 in 1" apparatus. A *dish* of water for each pupil, from which to supply the Apparatus or bottle, and in which many of the experiments are performed, is the only one absolutely necessary under all conditions. We mention several used for that purpose, that choice may be made according to circumstances. A somewhat expensive thing, but the best for private schools with small classes and well-fitted laboratories, is the glass battery jar, 6 inches in diameter and 7 inches deep, illustrated in EXP. **11**. A cheap substitute, which does very well, in fact just as well in most experiments, is a certain make of fruit jar, $5\frac{1}{2}$ inches deep and 4 inches in diameter, with a mouth of

$3\frac{3}{8}$ inches in diameter, illustrated in Exp. **23**. Two-quart fruit-jars, or large acid bottles, are easily cut off near the top, and make excellent water-jars. (See easy method of cutting bottles, Auxiliary Work.) Probably in most public schools the flaring 4-quart tin pail shown in Exp. **12** will be most satisfactory.

If work is done on sloping desks with lids, *blocks* to level the lids are better than books; if desk-tops are stationary and slope, *blocks* are necessary to level a tray on which to experiment.

A *tray* or *shallow pan*. As some water is unavoidably spilled, even the most careful pupil will usually need a pan, unless working on a specially prepared laboratory table, or where a little water is not objectionable.

Each pupil should bring from home a tumbler and a small towel, and keep them with his tin pail and pan. These four are all the extra articles needed for the regular experiments.

If any of the auxiliary apparatus is made, two tools are absolutely necessary, a round or rat-tail file and an awl. With these each pupil can make for himself several valuable additional pieces of apparatus, at no expense in money and but little in time. Corks for extra bottles are easily perforated with the file, so that tubes of the regular sets will fit. Small tin cans, such as those for baking-powder, spices, etc., are easily obtainable, and can be punched with the awl or nail; then the hole can be easily enlarged with the file until the tubes fit. With the rat-tail file holes are easily made through the "edge" of a bottle; then, with *care*, they may be rounded so that the rubber tubes will fit them. Where gas is available, two

other files should be supplied, — one a "three-cornered," the other a "half-round" file. A gas-jet bottle-cutter is furnished if desired but a file is needed to scratch the glass where the fine gas-jet is to cut it, and the half-round file to smooth the edges so that they will not cut the fingers. Keep the file wet when in use.

THE LABORATORY.

It is now conceded that the laboratory is one of the first essentials of every well-equipped school, outranking in importance even the library. The education there obtained is more practical, and of the kind to which civilization is chiefly indebted. That the laboratory has not found its way into every school is due, in part at least, to the usually great expense of its equipment and maintenance. It is believed that in this course, for one so valuable, the laboratory expense has been reduced to the minimum, and that in no school are the difficulties in the way of its introduction insurmountable. Not only the apparatus itself, but the other provisions for the work, may be more or less extensive, according to conditions. Pupils *can* do all their experimenting at home on the kitchen table, or wherever convenient. It *can* be done on ordinary school-desks, in trays, or shallow pans, levelled with blocks if the desks slope; the apparatus when not in use being kept in the boxes stacked in the corner of the room, or on shelves. In most schoolrooms, there are one or more walls against which narrow tables can be fastened with hinges, and, if in the way, let down when not in use, the cupboards or shelves for apparatus being placed above. If

there is not table room for an entire class, the class may work in sections at different hours, in which case sets of apparatus for one section is all that will be needed. It is advisable, however, when convenient, that a room, even though small, be set apart for laboratory work. Its fittings need not be elaborate, tables being the only absolute necessity, though water and gas are exceedingly convenient. Water must be provided in some way, even if it is brought in pails. Gas, or the Bunsen Blast Alcohol Lamp, also is a necessity if glass apparatus is to be manufactured. A jet for each one or two pupils of a section is very convenient; though much may be done with but one jet in the room, by using rubber tubing long enough to bring the gas to the table, where it may be connected with either a common or a Bunsen burner, or the glass-cutter, according to the work for which it is desired.

Appliances for the second part, which continues the study of air and water, but in a more decidedly quantitative manner, differ but little from those used for the first, some additional apparatus being required and furnished, though it is easily made by the teacher.

The study of heat *should* follow, and constitute a part of that of air and water, and so fit the pupil for the study, either in or out of school, of the constantly varying phenomena of the seasons, and such practical subjects as house-heating, ventilating, etc.

The teacher will perceive, by examination of the material selected and method employed, what the author has learned by experience, that this course is just as available for high- as for grammar-school pupils. It is for the beginner in physics, whatever his age or advancement in

other studies; the older or abler pupils can do more complete work, and perhaps accomplish in one or two months what would profitably occupy others for a year. This great elasticity and adaptability is one of the strongest features of the course.

PREFACE TO SECOND EDITION.

THE first edition of this book was issued in sheet form, with blank pages for notes, in accordance with the method pursued by the author in the school where the work was evolved. The persistent demand for it in regular book form has led to the change. The author has embraced the opportunity to make several revisions, in order to facilitate the work with large classes, and to adapt it still better to the capacity of grammar-grade pupils who have not had previous instruction in science. Care has also been taken to reduce the time required upon the part of the teacher in correcting the written work.

The alterations in the course are not radical, though they considerably improve it, especially for public-school use. They consist of the introduction of an illustrated list of the pieces contained in the "100 in 1" set of apparatus, to aid the pupil in becoming acquainted with his tools and their names; of twenty new cuts illustrating experiments; in several instances of more explicit directions and questions; of the omission of the lever experiment, and all applications of it in explanation of balancing forces in fluids, and the substitution of EXPS. 5 and 6; of some slight changes in both experiments and apparatus, to avoid the necessity of a pupil ever borrowing of his neighbor, or of two ever having to work together.

The latter desideratum is reached, and two very pretty and instructive experiments preserved (Nos. 22 and 23), by relegating them to the Auxiliary Course, in which case the teacher will decide when and how they shall be done, if at all. They may be omitted altogether if necessary; as, like most of the Auxiliary Experiments, they embody only applications of principles learned in the regular course. Aside from the manual training their construction gives, and the increased interest aroused, the Auxiliary Experiments are, educationally, of about the same value as mixed examples in arithmetic introduced at the proper time; hence the list might be abbreviated or entirely omitted.

THE AUXILIARY WORK.

The Auxiliary Experiments are placed in the back part of the book, and referred to whenever they would be of aid. Every reference to them should be looked up by both teacher and pupils, as frequently some help can be obtained thereby, even without the apparatus; but of more importance is the fact that frequently the auxiliaries are so simple that the pupil can easily obtain the material and do the experiments at home. Those requiring glass tubing should, if possible, be made by teacher or pupils in school. The method by which one Boston teacher makes use of the Auxiliary Work has produced such excellent results, and is probably so generally feasible, as to deserve mention. As soon as interest in the regular work was aroused, a small club was formed of the most interested pupils, for the purpose of fitting up a working laboratory. A small one-windowed room was the only place available

in the schoolhouse. This they supplied with a long, narrow table and a few shelves. They then taxed themselves to purchase a pound of glass tubing, a Bunsen burner, and two files, and came to me for a "gas-jet-glass-cutter." Bottles and corks were brought from home, and many pieces of apparatus constructed, which were exhibited to the entire class by their makers. As the room was small, and time for work limited to play-hours and Saturday, the teacher kept the "Laboratory Club" small by requiring a certain standard of excellence in regular work before a pupil was eligible to membership. The teacher reports that the plan has worked well, and he believes some of our future Edisons and Teslas are getting a start in the direction of their bent.

This entire Physical Science Course, Auxiliary Work included, has grown out of the individual method of teaching; and it makes the application of the method possible, and even easy, in large classes, where too frequently everything is machine-work, every pupil being required to do the same work at the same time. The method is a *discovery* method in more than one sense; not only does the pupil "discover" the principles of physical science, but the teacher discovers his pupils, and the course of work easily adapts itself to them all. The better pupils do more or less of the Auxiliary Work, according to their interest and ability. This feature of adaptability to different pupils shows itself more decidedly in the quantitative work introduced between the almost entirely qualitative work of the first seventy-nine experiments, and the Auxiliary Work. Two of the experiments in Specific Gravity give work severe enough for the very

ablest pupils, while the leading facts of all the other experiments can be obtained by all.

THE QUANTITATIVE WORK.

The twenty-two Quantitative Experiments are such as the pupil's previous work has prepared him to do, and such as will give him a much more thorough understanding of the subjects he has been studying; in fact, a fairly rounded-out conception of the physical properties of air and water, with the exception of the effect of heat upon them, which is considered later in connection with, or just previous to, their chemical composition. The first nine of these Quantitative Experiments (study of Pressure, Compressibility, and Expansibility of Air) require three pieces of apparatus not put in the pupils' sets, chiefly for the reason that one of each is amply sufficient for a class. These should be experimented with by the teacher before the class, or placed in convenient positions, where each pupil can use them in turn; or, better than either method (in the case of the first one at least) is a combination of the two. These pieces will cost about three dollars a set, more or less, according to the size of tubes used and consequent amount of mercury. Explicit directions for making and setting them up are given in an appendix.

METHODS OF CONDUCTING THE WORK.

These will differ according to circumstances, the chief "circumstance" being the teacher. Whatever method is adopted, this fact should be kept distinctly in view, that the object is not so much to teach physics as to train the

pupil in the true scientific method. Teach him how to study nature so that, should he be deprived of any further aid from the schools, he shall still be prepared to see and think for himself. The discipline thus gained will be of more value to him than would any amount of facts taken on trust, and the desire for a higher education will also be thereby increased.

First of all, he *must* do the experimenting himself, not only the manipulating of the apparatus, but the thinking out of what the experiment teaches. Hence the work must be *individual;* for then only can the pupil learn how to put questions to nature, and how to read the answers. Though a little something may be accomplished by the modern lecture-table method, in which the teacher does the experimenting, and the pupils the thinking and writing, especially where the conditions are most favorable, i.e., classes small, and pupils advanced and interested; yet even then the results are insignificant compared with those obtained by the *laboratory* method. But in the case of large classes of young pupils in various stages of immaturity, the former method not only fails to accomplish much with the best pupils, but for the vicious and indolent it affords opportunity for anything except attention to the lesson of the hour. For the best "manual-training" discipline somewhat extensive experience and observation have failed to show the writer anything superior, and but few things comparable, to *laboratory* physics. In physics thus studied the pupil is fully engaged, — hand, head, and heart; for he is always interested in experimenting, hence he has neither time nor disposition to stick pins into his neighbor. The physical training in manipu-

lating apparatus, that is neither too difficult nor too easy; the mental training in seeing what occurs and in connecting it with its cause, if the experiment is adapted to the mental condition of the pupil; and the moral training in engaging the entire child in the proper study of those laws under which he "lives and moves and has his being," — speak so loudly for the *laboratory* method, that we do not believe any true teacher who has ever tried it can be persuaded to adopt any other. The most important thing for the teacher to insist upon at the beginning, before the pupil sees the necessity for it, is that he makes haste slowly; that he obtains the principal fact taught by each experiment before doing the next. If the pupil's actual work is revealed to the teacher by what he writes (which was the author's method, supplemented by watching each pupil's experimenting so far as time permitted), his notes should be examined after every laboratory hour, and marked according to their deserts. The facts necessary to be discovered, and written at each lesson, are few; but the pupil must be held to them, however they are stated, or whatever else is written in connection with them. Here is an excellent opportunity to drill the pupil in making his statements in clear and concise language. More or less time should be given to this work according to the pupil's need.

The method of conducting this course developed in the Prince School of Boston meets such hearty approval that we have urgently requested its author — one of Boston's ablest grammar school principals, himself a teacher of physics for many years — to contribute an account of it, for the benefit of such teachers as desire to study a model method.

LETTER FROM PRINCIPAL YOUNG.

PROFESSOR BAILEY:

Dear Sir, — In reply to your inquiry as to the method pursued in the use of your "Course of Physics" in the Prince School, please find below a statement in regard to the same.

Believing in the inductive plan of teaching physics, and in the application of that plan as presented in your Course, I gladly availed myself of the opportunity to give it a trial.

The classes in which the trial was made numbered about forty pupils each. How to teach so many pupils at one and the same time, secure their earnest attention, be sure of their "grasping the idea" in the experiment at hand, and writing in respectable English the conclusions reached, and all this independently of one another, were difficulties that must be met and overcome, if the method was to find favor in large public schools. After a trial of a year, and the making of many changes in the adaptation of the method to such conditions, I am free to say that the difficulties above mentioned have disappeared, and the success of the Course seems to be assured.

Our final method of using the Course has been as follows: Each pupil has a desk of his own with a level top. It contains, besides the box of apparatus, a pan, a towel, and a tumbler. There is a pail for each desk, which is filled with water before the lesson begins.

During the EXPERIMENTAL LESSON, each pupil works independently and silently, guided only by the printed directions of the Course. In case a piece of apparatus is

broken by a pupil, he is allowed to raise his hand to attraet attention. The piece is at once replaced from one of the boxes near at hand, containing extra pieces.[1]

After performing an experiment, the pupil is required to write his conclusions on paper provided for the purpose, which must be given to the teacher before the next experiment is attempted. At the close of the hour, the work is stopped at once, every unfinished experiment or paper being left till the subject is again resumed. The papèrs, when finished as the experiments require, are numbered with bold figures in the upper left-hand corner.

They are kept for the TALKING LESSON given in the schoolroom, when enough papers have accumulated. These talking lessons are conducted by the pupils themselves, and are intended to provoke an animated discussion of the conclusions written during the experimental hour. Drawings of the apparatus used are made on the blackboard, questions asked and answered. In this way the faets taught through the experiments are drawn out, the teacher meanwhile guiding the line of thought, exciting further inquiry if need be, but avoiding at all times the giving of direct information

At the close of the talk the papers are rewritten on the back, and finally copied into blank books, care being taken to secure good expression of the facts learned. The books are marked, and the results reeorded.

[1] The amount of breakage varies not only with pupils of the same school, but with schools. It is, however, much less than is at first expected. The banner school in that respect, so far as heard from, is the Dearborn of Boston, Principal Chas. F. King. There forty-eight pupils used twenty-four sets of apparatus one year without breaking a cylinder, and so few pieces that it did not amount to an average of one cent per pupil.

The pupils are thus led, (1) to experiment for themselves, (2) to draw their own conclusions, (3) to write in every case before proceeding farther. (4) They are given an opportunity to interchange opinions, (5) arrive at proper conclusions by taking time enough to think over what has been done, and (6) are finally required to write out again their inferences in good English in blank books for inspection and marking. Such, in brief, is the plan pursued in this school.

A still further use of the Course may lead to other changes in the method as above presented, but at present the plan seems to accomplish all that is desirable; viz., interest in the subject, carefulness in manipulation, familiarity with principles taught, inquiry into nature's ways, and cultivation in the use of language.

Very truly,

E. BENTLEY YOUNG.

PRINCE SCHOOL, *June* 20, 1896

INDUCTIVE
ELEMENTARY PHYSICAL SCIENCE.

A LETTER FROM THE AUTHOR TO THE PUPIL.

MY DEAR YOUNG FRIEND:

I want to talk with you a little before we begin work — or play, I may as well call it; for tops, balls, and marbles are by no means the most interesting things we use in this fascinating scientific game. That it is as enjoyable as play to children of twelve to fourteen years I *know;* because the pupils in my Boston school, of their own accord, frequently use their recess-hour for it, and often come before school and on Saturdays in order to do more experimenting than their regular hours permit. That it is the very best way to learn about the world we live in, all the best teachers believe; because each pupil is learning directly from a better teacher than any living, — NATURE. Do you remember how Longfellow says that the great and good Professor Agassiz learned his lessons?

> "And Nature, the old nurse, took
> The child upon her knee,
> Saying, 'Here is a story-book
> Thy Father has written for thee.'

And he wandered away and away,
With Nature, the dear old nurse,
Who sang to him night and day
The rhymes of the universe.

And whenever the way seemed long,
Or his heart began to fail,
She would sing a more wonderful song,
Or tell a more marvellous tale."

Now I am going to ask you to adopt a motto that I write upon my blackboard the first day of every school year; viz., "NATURE is our teacher; all the knowledge we possess has come through the patient study of her laws." Then, whenever you are tempted to ask your *school*-teacher anything about Physical Science, I would ask you to stop and think, "Why, NATURE is my teacher; I must ask her." "But," say you, "I don't know how." That is true; and that is the reason I have arranged this series of questions (experiments) for you, in order to tell you how to ask them. If you do as I direct, you will not only be greatly interested and instructed by the answers you obtain, but, what is *far* better, you will learn how to put questions yourself. Then you will continue through life studying Nature wherever you are. You will become an original investigator, and possibly a discoverer and an inventor. All the great discoveries and inventions were made by men who first learned how to put their questions to this GREAT TEACHER, and interpret the answers.

Now let me tell you how to study this course, that it may afford you the most pleasure and profit. *First.* Perform every experiment in order. Do not omit one because

it looks so simple that you think you know all about it. None of us knows *all* about anything. *Second.* Always experiment carefully and thoughtfully. If you work hurriedly, carelessly, or without watching to see everything that happens, and without thinking out for yourself the reason for it, it will do you little or no good. And, of course, if you must not be told *why* anything happens, you should not tell your classmate, and so deprive him of the pleasure and benefit of discovering for himself. . Possibly you may perform an experiment and not see the *why* of it at first; if so, give it a little careful thought, remember the *what*, and perhaps the very next experiment will show you the *why*. If, however, two or three experiments do not help you out of your difficulty, probably you have not done the previous work well enough, and had better review it. *Third.* When you see what an experiment teaches, you must tell it in your own language on paper. It will not do you half the good to give it in spoken words; you must *write* it. Number each inference, — that is, what the experiment teaches you, — and write it at the time you do the experiment. Your thought being chiefly on the experiment and what it teaches, you will not express it in the very best language now without mistakes; therefore you should re-write it. Let me tell you our method, for it is the best we have yet discovered. After experimental work our pupils have an hour for writing the lesson; this they do on ruled note-books in the form of a chapter on science. Each lesson is dated; it begins at the top of a page, and is written only on the right- or else the left-hand side (always the same), the other being left for corrections. The experiment, observation, and

inference are given; the first is usually illustrated with a small drawing.[1]

The pupils preserve their books, and at the end of the year it is a good plan to have them bound. Pupils prize these books more highly than any others in their libraries, for they are entirely of their own making. What I ask you to do is one thing that did much towards the discipline of George Washington, for we are told upon good authority that "he made his own schoolbooks."

Hoping that you will do likewise, and meet with success through life, I am,

Your true friend and fellow-student,

F. H. BAILEY.

6 MARLBORO STREET, BOSTON, MASS.

[1] SUGGESTIONS FOR CORRECTING BOOKS. — After school I look over the work, and with red pencil mark the mistakes with such signs as *gr.* for grammatical error; *sp.* under word for misspelled; a wrong or unsuitable word or expression is marked underneath *u.w.* or *u.ex;* a statement that is wrong, or that had better be reconsidered and re-written, is enclosed in parentheses and marked with an interrogation point, thus (—)?. The next day the pupils correct their mistakes, changing nothing on the written page, but making the corrections directly opposite. Then the next time the books are inspected, if all corrections are satisfactorily made, an *A* (accepted) is placed at the top of the page.

STUDY OF APPARATUS.

"100 IN 1 PHYSICAL SCIENCE APPARATUS."

IT is very essential that you should know what articles are contained in your set of apparatus, and what each article is called throughout the book. Begin with No. 1; read its name, find its picture, and then the article itself in your box. Go through the entire list the same way. Nos. 1, 2, and 3 are shown in Fig. 1, but are not there numbered. A few common and easily recognized articles — Nos. 34 to 47 — are not illustrated. A few pieces of which there are several of a kind, are shown as they are connected for use. The small rubber balloon you are cautioned not to distend by blowing into it. These balloons are not always of the best quality, though we try to have them so. They come from Germany, and sometimes an entire shipment will be poor. However, the poorest are all right for the experiment for which they are intended; as they are not to be blown up, but only filled with in-rushing air. Another piece that is liable to be spoiled by abuse is the 4-inch square of sheet rubber. Use it only as directed. Do not try to see if it will stretch enough to cover your desk. It might not. Should you tear it, however, any dentist could supply you with a thinner sheet that will answer very well.

Those who desire to make their own apparatus will find directions in the Preface and in the "Auxiliary

Work" in the back part of the book. No. 1 of the list is called the "100 in 1 Physical Science Apparatus," because about a hundred experiments are performed with it and its various attachments. The experiments of which

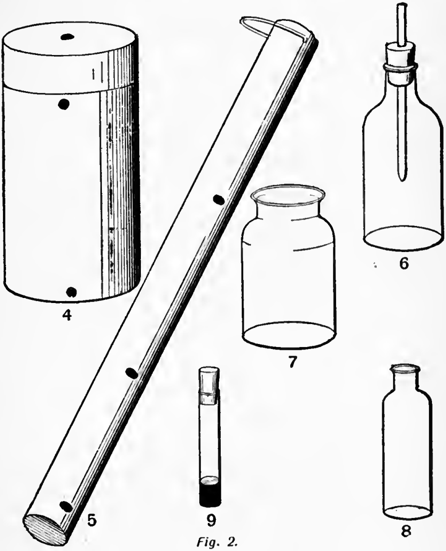


Fig. 2.

it is capable are not all given in this book, for the express reason that it is thought best to allow you the opportunity of inventing some. Throughout the book this piece is called the "Apparatus." Wherever the same word begins with a small "a" it does not refer to this particular piece, as in the first paragraph on page 5.

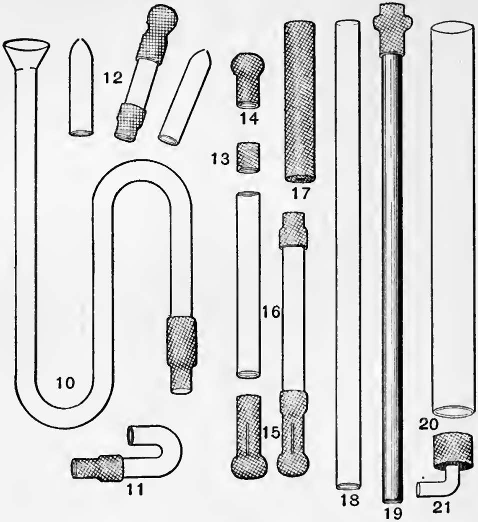


Fig. 3.

APPARATUS ILLUSTRATED.

No. 1. Apparatus.
2. Rubber Stopper.
3. 3 feet of Rubber Tubing.
4. Tin Can and Cover.
5. 12-inch Tin Tube.
6. Bottle and Attachment.
7. Wide-mouth Bottle.
8. Bottle Imp.
9. Vial of Mercury.
10. Pressure Gage with rubber connector.
11. Pressure Gage Attachment with rubber connector.

No. 12. 3 Short Jet-tubes; one with "packing" and "cap."
13. 4 pieces of Packing.
14. 4 Jet-tube Caps.
15. 2 Rubber Valves.
16. 2 Connecting Tubes; one with "packing" and "valve."
17. Heavy Rubber Tube.
18. 6-inch Tube.
19. Piston or Plunger.
20. Piston Tube.

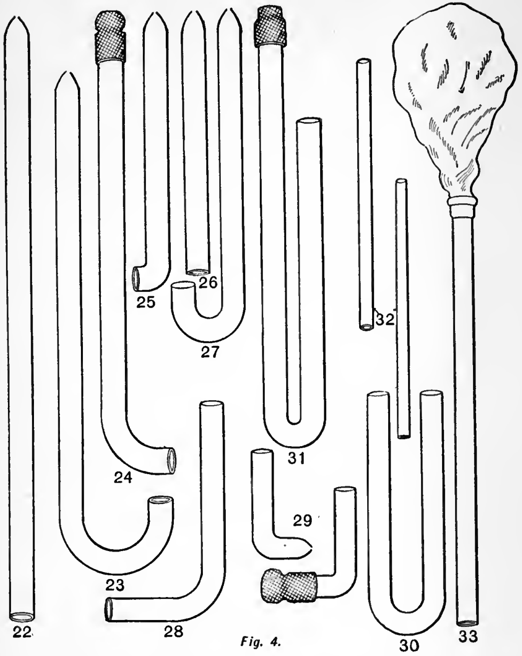


Fig. 4.

No. 21. Piston Tube Attachment; with "packing."
22. 8-inch Jet-tube.
23. 6-inch Curved Jet-tube.
24. 6-inch Elbow Jet-tube; with "cap."
25. 4-inch Elbow Jet-tube.
26. 4-inch Straight Jet-tube.
27. 4-inch Curved Jet-tube.

No. 28. Elbow Tube.
29. 2 Elbow Jet-tubes; one "capped."
30. Equal-arm U-tube.
31. Unequal-arm U-tube; with "packing."
32. 2 Fine Tubes.
33. Rubber Balloon and 6-inch Tube.

APPARATUS NOT ILLUSTRATED.

No. 34. 4 Glass Marbles.
35. Wooden Ball.
36. 4 "2 Buck Shot."
37. 4 "Single F." Shot.
38. Sheet Rubber, 4 in. sq.
39. Square of Cheese Cloth.
40. 2 in. sq. Wire Cloth.
41. 2 in. sq. Glass.

No. 42. 2 in. sq. Tin.
43. 2 in. sq. Card.
44. 2 in. sq. Wood.
45. Shot Punch.
46. 1-inch Rattan.
47. Cork, Stick, String, and Rubber Bands.

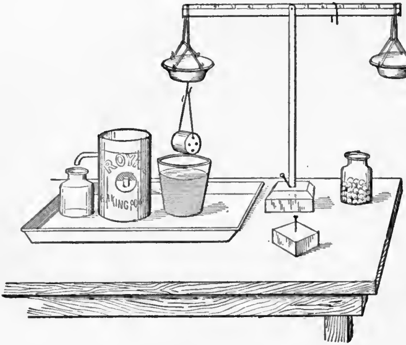


Fig. 5.

ADDITIONAL APPARATUS FOR QUANTITATIVE WORK.

TO PUPILS' SETS.

No. 48. Scales, Block, Rider, and Apparatus Hook.
49. 25 Gram Weights.

CLASS PIECES.

No. 50. Barometer with Mercury.
51. Balancing Liquids, Tubes, and Mercury.
52. "Boyles' Law" Piece and Mercury.

FIRST EXPERIMENTAL WORK.

DIRECTIONS FOR ADJUSTING THE "100 IN 1 PHYSICAL SCIENCE APPARATUS."

It is useless to attempt to perform the experiments of this course without first learning how to manipulate the apparatus. You should follow these directions carefully, and practise them until the pieces of the apparatus can be put together and taken apart properly and readily; then the experimenting will become easy, pleasurable, and profitable.

First remember that in every experiment, unless otherwise directed, the holes in the "100 in 1 Apparatus" (see illustration to Exp. 2), or in the bottle used instead (see illustration to Exp. 9); also in the rubber stopper, should be plugged. To plug the hole in the bottom of the Apparatus or bottle, stand it bottom upwards; wet thoroughly a ¼-inch piece of rubber tubing or "packing;" insert just barely into one end a shot (the smaller of the sizes furnished with the set) large enough to slightly stretch the "packing;" thrust the free end into the hole until the shot-loaded end is even with the outer surface; then with the thumb push the shot well into the packing. If the packing is not inserted far enough to allow the Apparatus to stand steadily, it is not well done; and, as it is scarcely possible to push the rubber in farther after

the shot has been crowded in, both shot and packing should be removed, and another trial made. In fact, trials should be made until this method of plugging can be easily and properly done every time. To remove the shot and packing, first stand the Apparatus inverted in the pan, then push them through with the nail. The holes in the side of the Apparatus may be plugged, and the plugs removed in the same way, except with the Apparatus lying upon its side. As it does not matter if the rubber packing projects from the side holes, the shot may be pushed farther into the packing before it is inserted than when used for the bottom hole.

The side holes may be plugged with the small glass jet-tubes (see Exp. 2) as follows: Wet a "cap" or ½-inch piece of rubber tubing with a shot in the end, and push it over the small end of the jet-tube; put a piece of packing just barely over the other end; then seizing that part of the packing stretched by the glass, push it into the hole, and then with a twisting motion thrust the tube in until it is held firmly.

To connect *any* glass tube with the Apparatus, put a piece of wet packing over the end of the tube; grasp it at the place where the rubber is distended by the glass; insert the packing into the hole, and then push in the tube with a twisting motion until it is held firmly. If the rubber packing is pushed clear through the hole, — which may happen if the glass tube is the least particle smaller than it should be, — thrust the end of the glass tube a little farther into the packing, wipe the outside of the latter dry, and try again.

To remove a jet-tube or other glass tube from a hole,

seize it firmly near the packing, and draw it out with a twisting movement.

Never leave glass tubes connected with the Apparatus. Never leave shot inside the packing; as it is hard to remove when dry, though very easy when wet. Never *remove* the shot from the caps or valves. Never leave wet packing, caps, or other rubber on a glass tube; after drying they are apt to stick to each other so firmly that they are not easily separated. The glass tubes are not very easily broken, and with decent care there is no need of ever breaking one.

If the long piece of rubber tubing has been used with water, blow the latter out before putting the tubing away. The sheet rubber should be dried with a cloth.

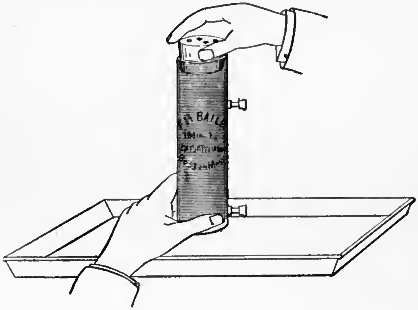
Do not attempt to perform any experiment in a careless, slipshod manner. If you are not careful and orderly, you cannot hope for success in any pursuit. Begin now by being careful of your apparatus. Try to be exact; always do your work neatly; and always put your apparatus away in good order when you have finished your work.

WATER EXPERIMENTS.

Experiment 1. Fill the Apparatus, or bottle used instead, to the brim with water, and insert a finger.

OBSERVATION. What happens?

INFERENCE. Why?



Exp. 2.

Exp. 2. Fill the Apparatus with water; crowd a large shot into each hole in the smaller end of the rubber stopper, then try to insert it into the Apparatus.

OBSERVATION AND INFERENCE.

Exp. 3. Remove the shot from the stopper, then insert it into the Apparatus.

OBSERVATION.

Inferences. 1. Why can you easily insert it now? 2. What do these three experiments teach you about water that is also true of everything you can see or handle?

Exp. 4. Weigh the Apparatus; fill with water, and weigh again. (The weight may be estimated if scales are not accessible.)

Observation.

Inferences. 1. What does this experiment teach about water? 2. Would it have weight if there were no force pulling or pushing it towards the earth? 3. Is it the same force that causes a ball thrown upward to fall back to the earth? 4. Do you know its name? (It has a name, but we do not know much about it.) 5. Towards what point in the earth does this force pull everything on the earth? 6. Draw a circle to represent the earth, and illustrate the direction in which objects fall on different sides of the earth, showing where they would meet if they could fall through the earth as easily as through air.

Exp. 5.

Exp. 5. 1. Push the marble equally from opposite directions. 2. Push harder with one finger than with the other. 3. With thumb and finger of one hand press equally upon opposite points, and, with thumb and finger of the other hand, press equally upon opposite points half way between. 4. Press equally with both thumbs and

one finger, but harder with the other finger. 5. Seize your pencil with both hands, and pull equally with each. 6. Pull harder with one hand than with the other. 7. Pull with one hand only.

INFERENCES. 1. When and in what direction do things move? 2. When do they remain at rest?

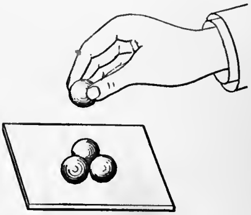
Exp. 6. Hold a marble an inch or two above the pan, and let go of it. Place it at one end of the pan, then raise that end a little.

INFERENCES. 1. How many forces were acting upon it while you held it? 2. Why did it drop? 3. Was it pulled or pushed towards the earth? 4. After it came to rest, was it still pulled or pushed, and if so, why did it not move? 5. Why did it move when the pan was tilted?

Exp. 7. Cap the small ends of the jet-tubes, and insert them in the side holes of the Apparatus. Fill it with water, and remove the cap from the lower jet-tube.

INFERENCE. In what other direction than downwards does water press?

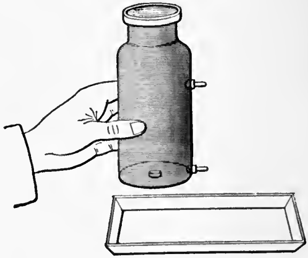
Exp. 8. Upon three marbles, touching each other on a smooth surface, place a fourth.



Exp. 8.

INFERENCES. 1. What causes the three to roll apart? 2. Now explain why water presses *sideways*. 3. Do other liquids press sideways? 4. Do solids press sideways? 5. If you should hold your hand beside the wall of a brick house, would the bricks press sideways against your hand? 6. If you

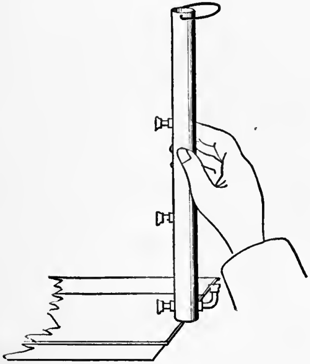
had a barrel full of marbles, fine shot, or of fine, dry sand, and you bored a large hole near the bottom, what would happen? If fine, dry sand is convenient, with a finger over the lower hole, fill your Apparatus, then remove the finger, and see how strikingly the stream of sand resembles one of water. 8. When do solid substances act very much like liquids? 9. What is the difference between a solid and a liquid?



Exp. 9.

Exp. 9. Cap the jet-tubes, fill the Apparatus with water, hold it above the pan, and uncap both jet-tubes.

INFERENCE. What more does this experiment teach you about *side pressure* than did Exp. 7?



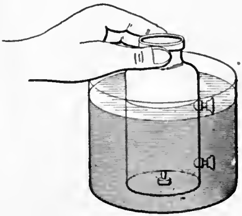
Exp. 10.

Exp. 10. Insert capped jet-tubes in three holes of the long tin tube, plug the other hole with a capped elbow jet-tube as illustrated, and fill the tin tube with

water. Uncap the three straight jet-tubes. Study also Aux. 1.

Inference. What more do these experiments teach you about side pressure than did Exp. 9 ?

Exp. 11. Insert into the bottom hole of the Apparatus a short jet-tube with small opening inside, and press the Apparatus well down into a jar or pail of water until a fountain is produced.



Exp. 11.

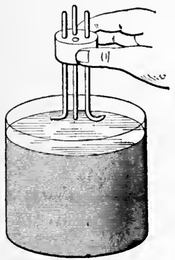
Exp. 12.

Inference. In which direction does the water press ?

Exp. 12. With bottom hole open, place a card over the mouth of the Apparatus, invert, and press it down into the water. Repeat, using a disk of metal (iron, zinc, or lead), and also one of glass. The metal and glass disks must be held against the Apparatus till immersed an inch or two. (If, instead of a tin pail, you are using a jar not large enough to admit the hand, keep the disk in place by means of a string or wire passed under it, the ends being held in the hand.) As the water leaks in until the disk finally falls, compare its height inside and outside of the Apparatus.

Inferences. 1. What forces here act in opposite directions? 2. Which force is the greater until the disk falls? 3. Why does not the disk move in obedience to the greater force? 4. Which force is being constantly increased until it overcomes the greater, and how is it increased? 5. Why must a heavy disk be immersed deeper than a light one in order to be held up at all? 6. Is there any resemblance between the law for water pressure upward and sideways? 7. What do you think causes upward pressure in water? 8. Do you think that upward pressure is the same, or that it exists at all in other liquids?

Exp. 13. Thoroughly wet the rubber stopper, then insert the three 4-inch jet-tubes as illustrated, with the lower openings all at the same level. Immerse the lower ends of the tubes in water, and notice in which direction the water must press in order to enter each; observe the height to which water rises in each. Be sure that the upper jet ends of the tube are not stopped with water.



Exp. 13.

Inferences. 1. Compare pressure in all directions at the same depth. 2. Compare with Exps. **9**, **10**, and Aux. **1**, and tell what you can without more experiments about upward pressure at different depths. 3. How does upward pressure two inches below the surface compare with upward pressure one inch below?

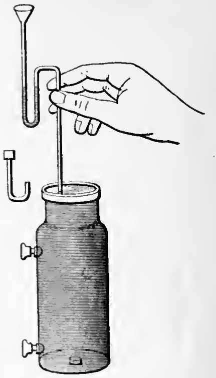
Note. — The right arm of the pressure-gage in the "100 in 1" set of apparatus is considerably shorter than is shown in the cut; it must be lengthened by one of the 6-inch pieces of straight tubing and a rubber connector.

Exp. 14. Fill the bend of the pressure-gage two-thirds full of water, and slowly insert the lower end several inches into the Apparatus or dish of water.

INFERENCE. Does this experiment prove that your second inference in EXP. 13 is correct?

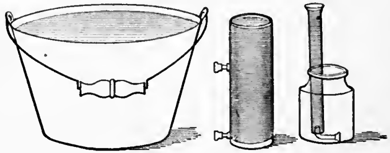
Exp. 15. With the attachment on the lower end of the pressure-gage, repeat above experiment; also attach the elbow-tube and repeat.

INFERENCE. Do these results confirm your previous inferences about pressure sideways and downward?



Exps. 14 and 15.

Exp. 16. (See AUX. 2.) Insert pressure-gage to the same depth in water contained in dishes of various *sizes* and *shapes*.



Exp. 16.

INFERENCES. 1. Upon what *one thing only* does the upward water pressure against the air in the gage depend? 2. Would it be any greater at the same depth in a lake or pond? 3. Upon what *two things* does the downward pressure upon the bottom of a dish full of water depend? 4. Is

the pressure on the bottom of dish **2**, below, greater than that on dish **1**? 5. How do you know? 6. Is the pressure on the bottom of either dish just equal to the weight of the water it contains? 7. In the other, is it greater or less than the weight of the water? 8. With dish **3**, how does the pressure on the bottom compare with that of the others? 9. Why? 10. How does the pressure compare with the weight of the water? If the inside of dish **1** is just **1** foot

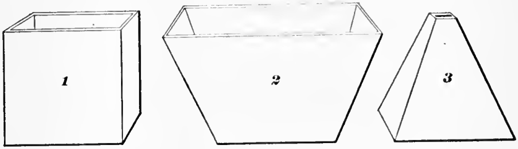


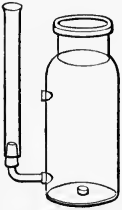
Fig. 6.

square on each side, it will hold 62.5 lbs. of water. **11.** What is the pressure against one side of the dish, if full of water? **12.** What is the total pressure against the sides and bottom? **13.** What is the total water pressure against sides and bottom of a dish twice as long, but the same width, and holding the same amount of water? Make a drawing of the dish, or a diagram of the bottom, one side, and one end. **14.** A dish is twice as long and twice as wide as No. **1**, but holds the same amount of water. What is the total water pressure on bottom and sides? Draw or diagram the dish. **15.** What is the depth of each dish? **16.** As a general fact, is the *total* pressure of a certain amount of water more if held in a deep dish with small bottom, or in a shallow dish with large bottom? **17.** A deep dish and a shallow dish, both with perpendicular sides, hold each the same amount of water; how does the pressure on their bottoms compare?

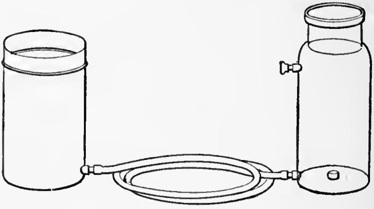
That which belongs to you is called your property. Call anything that belongs to water its property, and tell briefly what properties of water you have thus far discovered; also state the two leading facts about water pressure. By use of these facts explain the following experiments.

Exp. 17. Fill the Apparatus with water, and observe the tube.

INFERENCE. Explain *why* liquids "seek their own level."



Exp. 17.



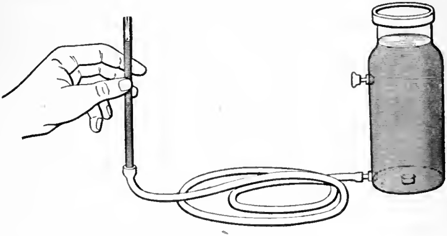
Exp. 18.

Exp. 18. Connect the Apparatus and tin can by means of packing, connecting-tubes, and long rubber tube; pour water into one, and watch both. Raise and lower one, watching effects. Place them close together, near the edge of the table or desk, with the rubber tube hanging over, and fill one with water. Vary their relative positions and the position of the tube as much as possible. Note and explain fully whatever takes place.

OBSERVATION AND INFERENCE.

NOTE. — Did you ever see a carpenter's spirit-level? If so, compare it with the water-level (AUX. **3**) and with EXP. **18**: if not, find one, and study it as soon as convenient.

Exp. 19. With the Apparatus full of water, raise the jet-tube till it contains no water, then lower it till a fountain is formed.



Exp. 19.

INFERENCES. 1. Explain how water from reservoirs is supplied to towns and cities. 2. Why are reservoirs built on hills? 3. Why do cities located in level countries build standpipes or water-towers? 4. On which floor of tall buildings thus supplied with water does it escape most rapidly, and why? Write about this subject as fully as you can, and see if you can apply the same principle to explain country water-supply by wells or springs. (See AUX. 4.) Explain water-supply as shown in Fig. 7.

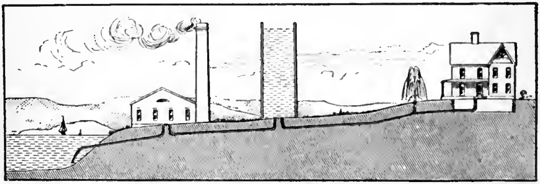
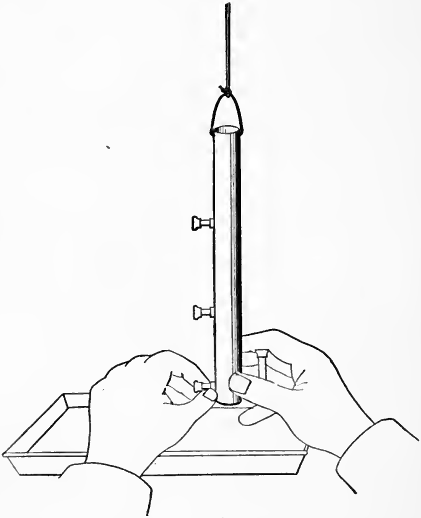


Fig. 7.

NOTE. — EXPS. **20** and **21** require a high point of suspension. Where it is not convenient to arrange a hook directly above each pupil's desk or table, a few hooks and strings should be provided where pupils can go in turn or in very small groups, to experiment. Usually hooks may be inserted into the top of window-casings, and strings attached, reaching to within about one foot of the window-sill. (See AUXS. **4** and **5**.) As the Apparatus is not tall enough to make these experiments very striking, the 12-inch tin tube is provided.

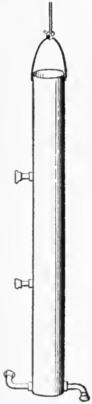


Exp. 20.

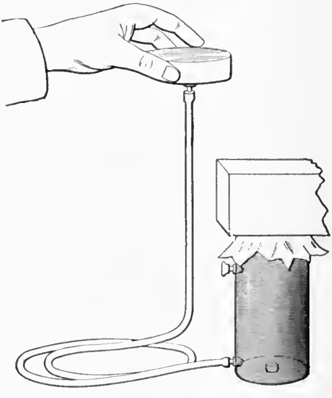
Exp. 20. Suspend the tin tube as illustrated by as long a string as possible just above a table or a window-sill. Steadying it with one hand, carefully remove both cap and tube together from one lower hole with the other hand, and let go of the tube at the same time.

INFERENCE. Why does the tube swing away from the jet of water?

Exp. 21. With the tube still hanging, insert elbow jet-tubes in both of the lowest holes so as to point in opposite directions, and fill with water. Experiment in a variety of ways, thus: with both jet-tubes horizontal and the tin



Exp 21.



Exp. 22.

tube hanging within a pail to catch the water; with one tube horizontal, the other at any angle; with tubes at different angles imitating a lawn fountain; with both tubes horizontal and under water; etc.

INFERENCE. At exactly what point or points is the pressure applied that causes the rotation?

Exp. 22. Fill the Apparatus and rubber tube with water. To fill the latter, let it lie on the table, and pour

water into the Apparatus; then, when the water begins to run out of the tube, plug the end with capped jet-tube. When the Apparatus is as full as possible, tie the piece of sheet rubber over the mouth, and place a weight of about a pound upon it. Insert a funnel in place of the plug. Pour water into the funnel (see note to AUX. 6), and raise it to the length of the tube.

INFERENCE. Explain why so little water raises so heavy a weight. See AUX. 6.

Exp. 23. Alternately lower and raise the stopper, and see if you can tell with your eyes shut when it enters or leaves the water. Try also the wooden ball.

Exp. 23.

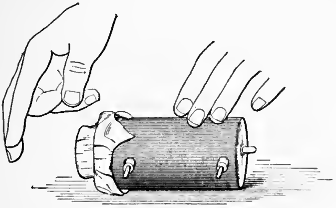
INFERENCE. Explain as fully and carefully as you can why the stopper when under water seems to weigh less, and why the ball floats.

NOTE. — Later in our course we shall have several interesting experiments similar to this; but you ought to see clearly *now* what causes this *buoyant* force of water, as it is called. Is a fish or a stone as heavy in water as it is out? Explain.

Exp. 24. Push the Apparatus along the table with your pencil.

INFERENCE. In what one direction only is the pressure which your hand applies to the pencil transmitted to the Apparatus?

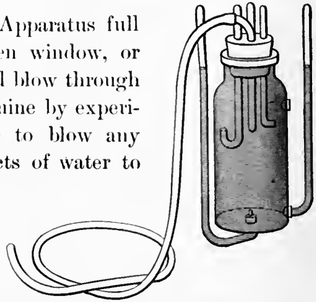
Exp. 25. Place capped jet-tubes in the side holes of the Apparatus, and plug the bottom hole with shot and packing. Completely fill it with water, and fasten the sheet rubber over the mouth with a string. Invert, push the shot inside with the shot-punch, and put a capped jet-tube in its place. Lay it down, as represented, with jet-tubes all the same distance above the pan or table, remove the jet-caps, and tap gently on the rubber with your fingers.



Exp. 25.

INFERENCE. Compare with EXP. **24**, and explain the difference between solids and liquids in *transmitting* applied pressure.

Exp. 26. With the Apparatus full of water, step to an open window, or any convenient place, and blow through the rubber tube. Determine by experiment whether you have to blow any harder to raise several jets of water to a given height than to raise one. See AUX. **7**.



Exp. 26.

INFERENCE.

NOTE. — When conditions are favorable, a very pretty variation of EXP. **26** may be made by combining it with AUX. **4**, using varying numbers of jet-tubes, and varying the height of the Apparatus.

Exp. 27. Fill the Apparatus with water, insert the stopper tightly with one hole open, and measure the part of the stopper above the glass. Carefully push the piston-rod or "plunger" through the open hole to the bottom, and again measure. The measurements should be made with care.

Exp. 27.

INFERENCE.

Exp. 28. Arrange the Apparatus the same as in Exp. **27**, but insert a short jet-tube in one hole of the stopper. Hold the palm of one hand about two feet above; seize the piston-rod at a point where the plunger end, when pushed in, will not quite reach the bottom of the Apparatus; then push it down suddenly.

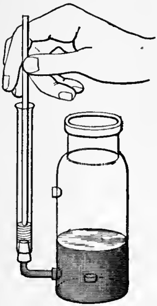
INFERENCE.

NOTE. — In doing Exp. **29**, insert the tube into the Apparatus farther than is shown in the cut, and grasp both together with one hand while working the piston with the other.

By "size" of a tube is meant the size, not the length, of the hole. If one tube is ten times as large as another, and both have the same depth of water in them, the first will contain ten times as much water as the second, and the surface of the water will be ten times as great.

Exp. 29. Withdraw the piston to the top of the tube, measure the length of the tube thus filled with water, and also the depth of the water in the Apparatus. Push the

piston to the bottom of the tube, and find how much the water from the tube increases the depth of water in the Apparatus. If the piston is not air-tight, fill the tube and the Apparatus with water, cork the tube, then pour nearly all the water from the Apparatus, and measure. Uncork and measure again.



Exp. 29.

INFERENCES. 1. The Apparatus is how many times the size of the tube? 2. With one pound pressure on the surface of water in the tube, how many would be required on the water surface in the Apparatus to balance? See AUX. **8.**

Exp. 30. Fill both the Apparatus and the tube with water, as in EXP. **22**, and tie sheet rubber over the mouth. Place weights of four or five pounds on the Apparatus, and blow into the tube.

INFERENCES. 1. Why can you lift so much with so little force? 2. How would you determine the number of pounds lifted by an ounce of force applied through the tube? By blowing through the tube you can apply only about an ounce of pressure.

PRACTICAL APPLICATION.

This picture illustrates the "hydrostatic" or water-press, a machine which enables one with but little force to exert great pressure. A pump stands in an open tank of water. In the pump, a little above the level of the water in the tank, is a closed door-shaped valve, which

opens upward when the piston is pulled up, allowing water to enter and fill the pump. Why it does so, you probably cannot see at present, but you will when you study the next subject, — Air. In the pipe connecting the pump and the press is a valve opening towards the latter. When the piston of the pump is pushed down, of course the pump-valve closes; and as the water cannot be

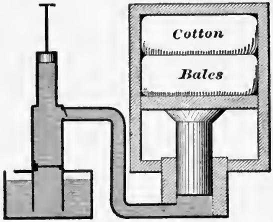


Fig. 8.

pushed out the way it came in, it goes through the other door to the press.

INFERENCE. Upon what fact about liquids does the great power of this press depend?

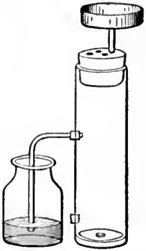
While performing the previous experiments, you have learned something about the so-called physical properties of water. You can also mention one force that has a great deal to do with these properties. There are other forces always operating which you will discover in connection with the study of the next subject, — Air. Before beginning the study of air, it would be advisable that you state again, clearly and briefly, all you have discovered about water.

AIR EXPERIMENTS.

Exp. 31. Plug holes in the Apparatus, and all but one in the stopper; in this insert funnel, and fill it with water.

Observation and Inference.

Exp. 31.



Exp. 32.

Exp. 32. With bent tube in the side of the Apparatus, opening under water in a dish, fill the funnel with water.

Observation and Inference.

Exp. 33. Float the wooden ball on water, invert the Apparatus or a tumbler over it, and press it well down into the water.

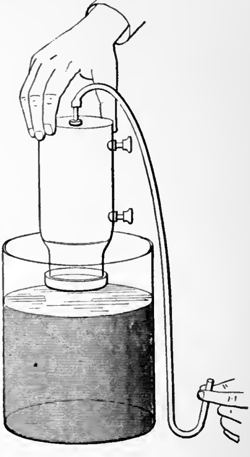
Observation.

Inferences. 1. What fact about air do these three experiments teach? 2. Compare with the first learned about water.

Exp. 34. Push the inverted Apparatus down into the water. Blow gently through the tube, and you have a miniature diving-bell.

INFERENCE. Why does not the upward pressure of the water force it up into the Apparatus? See AUX. **9**.

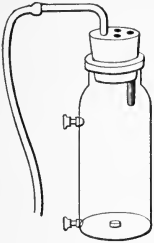
NOTE. — The lack of delicate scales makes EXP. **35** impossible in most schools, hence the teacher should construct AUX. **10**, and use instead.



Exp. 34.

Exp. 35. Plug every hole in the Apparatus (or use a large bottle), and every hole but one in the stopper; in this insert a short glass tube, and attach to it a short rubber tube with a plug in the end. Balance the Apparatus or bottle on scales, then remove the plug, and suck out all the air you can. Pinch the tube to prevent air entering whenever you stop to rest your throat, and stop sucking when you can exhaust no more air; also be careful not to let water from your mouth enter the tube, as a few drops might spoil the experiment; replace the plug, and return the Apparatus or bottle to its scale-pan. If the scales are delicate enough, and you have performed the experiment well, it will weigh less than before.

INFERENCE. Compare with this the second fact learned about water. For cheap but excellent home-made apparatus for this experiment see AUX. 10.



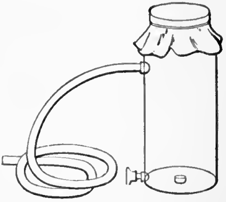
Exp. 36.

Exp. 36. Insert the stopper tightly in the Apparatus, pour mercury into the hole partly filled by the rattan plug, and suck air from the Apparatus. (Do not allow mercury to touch a gold ring.)

INFERENCE. What causes the mercury shower? See AUX. 11.

Exp. 37. Fill the Apparatus with water, and place a piece of card over the mouth. With one hand hold the card in place, while inverting the Apparatus with the other over a dish, to catch the water if the experiment should fail. Remove your hand from the card. In the same way repeat with disk of wood, metal (iron, zinc, or lead), and glass. Repeat, using a piece of wet cheese-cloth, or silk veiling, and wire netting. Repeat again, and uncap the jet-tube near the bottom of the Apparatus.

INFERENCE. See AUX. 12.



Exp. 38.

Exp. 38. Tie sheet rubber over the mouth of the Apparatus, and attach the long rubber tube to either side hole. Suck a little air from the Apparatus, and pinch the rubber tube to prevent its returning. Turn the mouth of the Apparatus in every direction.

INFERENCES. 1. What more about air pressure does this teach you than did Exps. **36** and **37**? 2. Compare with water pressure. 3. What force causes it?

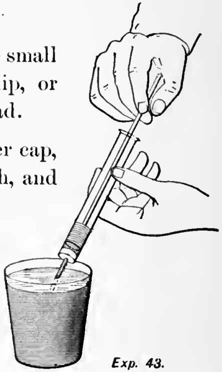
Exp. 39. Use your hand instead of the sheet rubber, and suck out all the air you can. Turn your hand over and in every direction. If the experiment is well done, the Apparatus will not fall off. You can hardly pull it off.

INFERENCE. Why?

Exp. 40. Suck the air from the small bottle, and stick it to the upper lip, or else try the next experiment instead.

Exp. 41. Wet a jet-tube rubber cap, squeeze it with your fingers or teeth, and press the tongue against the open end. If well done, you cannot shake it off.

INFERENCE. Why?



Exp. 43.

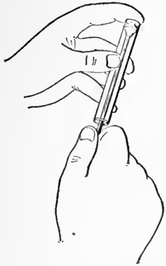
Exp. 42. Fill the Apparatus with water, and tightly insert the stopper with all the holes open, after which plug them with the shot. Though the stopper may be easily twisted around in the Apparatus, it is pulled out with great difficulty.

INFERENCE. Why?

Exp. 43. Wet the inside of the tube and wrapping on the piston-rod. Pull up the piston.

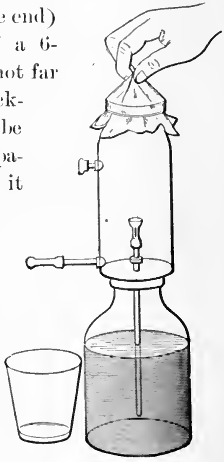
INFERENCE. Why does water follow it in the tube?

Exp. 44. (To be omitted if the pupil is not willing to pound his finger a little.) Wet the inside of the tube and the rubber on the rod, then insert the rod, and hold the Apparatus as illustrated. Press the finger tightly against the end of the tube, pull the rod about half-way out, and holding it in the centre of the tube, let go of it.



Exp. 44.

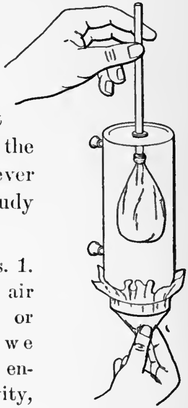
Exp. 45. This experiment illustrates how we pump water. Put a valve (a short slit rubber tube with shot in one end) on one end of a 6-inch tube, but not far enough to open the slit. With packing on the other end, insert the tube into the bottom hole of the Apparatus from the mouth. Push it through carefully, so as not to open the slit till you can seize the end below, and draw it the rest of the way. Connect the other valve, slit downward, to the Apparatus as illustrated, and tie the sheet rubber over the mouth. Seize the sheet rubber in the centre, pull up and push down alternately, and pump water from a bottle or pail.



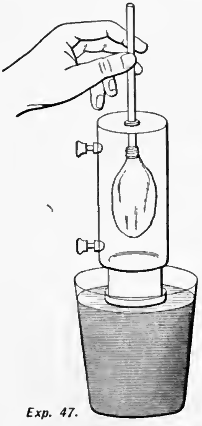
Exp. 45.

INFERENCE. Explain the best you can now, and better after you learn more about air. See AUX. 13.

Exp. 46. This experiment illustrates how we breathe. The Apparatus represents the chest cavity; the rubber balloon, the lungs. Alternately pull out and push in the centre of the sheet rubber tied over the mouth of the Apparatus. Of course in our bodies there is no such space surrounding the lungs filled only with air, also the chest is enlarged by a different method, but the physical fact is the same. Did you ever see a bellows for blowing a fire? Study the illustration of one on next page.


Exp. 46.

INFERENCES. 1. Do we "draw in" air through the nose or mouth when we breathe, or simply enlarge our chest cavity, and let nature do the rest? 2. Do you think there is any such thing as suction?


Exp. 47.

Exp. 47 is nearly the same as EXP. **46,** only it is performed by using water instead of sheet rubber. First fill the balloon with air, then alternately lower the Apparatus, into water a short distance, and withdraw it. See AUX. **14.**

Exp. 48. Tie the sheet rubber over the mouth of the Apparatus, and put a jet-tube into each hole, as in

Exp. 25. Strike on the rubber, and feel the air at the holes.

Inferences. 1. Compare with pressure transmitted by water. See Aux. 15. Compare what you have learned about air with what you learned about water. 2. What like properties do they possess? 3. Have you discovered anything which air will do that water will not? 4. If so, tell what it

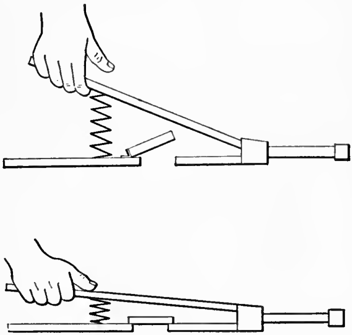
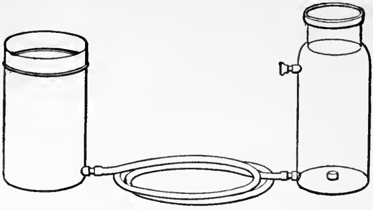


Fig. 9.

is, and where you discovered it. 5. If you have not, after telling in what respects air is like water, tell as well as you can how it differs from water. Then try the following experiments, explaining all you can by means of facts already discovered, but *keep your eyes open for new facts* about either air or water.

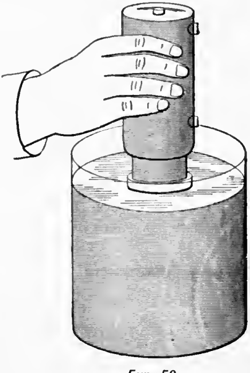
Exp. 49. Connect the Apparatus and tin can by means of the rubber tube. Put the stopper into the Apparatus, and fill the can with water. Fill both, put a stopper into the Apparatus, and empty the water from the can.



Exp. 49.

INFERENCE. Why does not the water run in either case?

Exp. 50. 1. With the bottom hole open, lower the inverted Apparatus into a dish of water till it is full, then



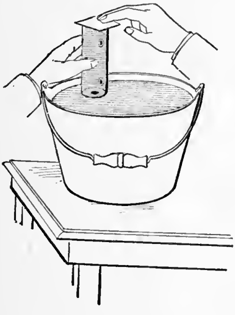
Exp. 50.

plug the hole, or cover it with the ball of your finger, and lift it nearly out. 2. While full of water, and held with the mouth only under water, open the bottom hole.

INFERENCES. 1. Why did not the water run out? 2. Why did the water run out?

Exp. 51. With mouth and bottom hole open, and the Apparatus erect, sink it beneath the surface in a dish of water, and when filled, cover the mouth with a card, held firmly in place. Then lift it nearly out of the water.

INFERENCES. 1. Does the water press up against the card? 2. If so, which presses the harder, water underneath or air on top? *Be sure* to write your opinion before trying the next experiment. Be careful, for even older pupils frequently make a mistake in answering this question when not allowed to find out by experiment.



Exp. 51.

Exp. 52. Repeat the last experiment, using, instead of the card, sheet rubber, tying it firmly over the mouth of the Apparatus.

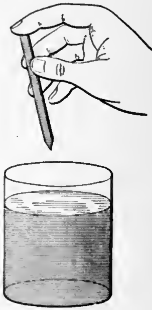
INFERENCES. 1. Did you answer the question in EXP. 51 correctly? 2. Explain this one as fully as possible, remembering that the elasticity of the rubber is one force operating to produce the balance.

Exp. 53. Fill the 4-inch jet-tube under water, and with finger pressing against the larger end, lift it out of water. Raise the finger a trifle, and replace it quickly. Repeat till the water has nearly all dropped from the

tube. Try a tube with large opening at each end. Try the largest tube.

INFERENCES. 1. Explain carefully. 2. Explain also why the water does not all run out. 3. If the water did not adhere to the glass, would or would it not all run out?

Exp. 54. Use all the different *sized* tubes you have as in EXP. **53.** Also, wet them inside, and hold them with one end in water and the other open.

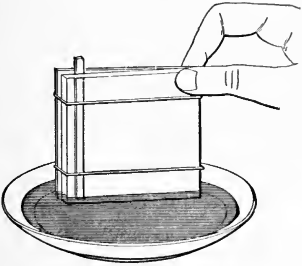


Exp. 53.

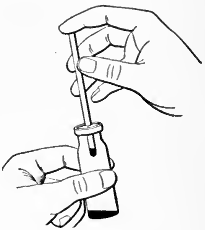
INFERENCES. 1. How does the length of the water column compare with the size of the tube? 2. Is it not the same force that makes a postage stamp stick to the envelope, or chalk stick to the blackboard? 3. Are you not using the same force when answering these questions in your books? 4. Give other examples. We call the force which causes particles not alike to stick to each other, *adhesion;* but if the particles which stick together are alike, we call the force *cohesion.* 5. Which force do you overcome when you break a stick or a string? 6. Do both of these forces act in holding water in a glass tube? In tubes, especially when they are small, whether glass or not, we call the force *capillary attraction,* from the Latin word *capillus,* meaning hair. 7. Now, using the word *cohesion,* explain one difference between solids (such as glass, wood, iron, etc.) and liquids (such as water, oil, etc.). 8. When water becomes a solid, or ice, has it more or less cohesion? 9. What force appears to be the opposite of cohesion? 10. What changes ice to water? See AUX. **16.**

Exp. 55. With a *clean* disk of glass and one of metal (or two of glass), a match, and two rubber bands, construct the apparatus illustrated. Immerse in water to wet the inner surfaces of the plates, then stand in shallow water.

INFERENCES. 1. Illustrate with a drawing, and explain. 2. Look also for a result of the same force in a tumbler of water.



Exp. 55.



Exp. 56.

Exp. 56. Place a small tube in the mercury in the small bottle. Also use the tube with mercury as a dropper.

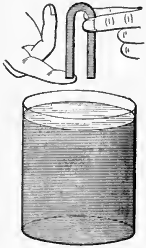
INFERENCES. 1. Illustrate with drawings. 2. Compare the two forces in this case with the same in case of water and glass.

Exp. 57. Fill the equal-arm U-tube with water; with the finger cover one end, invert, and, holding it perpendicularly, remove the finger.

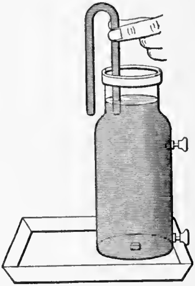
INFERENCES. 1. Infer why the water does not fall out. 2. Name all the forces you can that are operating in this

experiment. 3. Do they all assist in holding water in the tube, or not? Repeat the experiment, using U-tube with unequal arms. Repeat again with first U-tube, inclining it till the water runs out.

Exp. 58. Fill the U-tube with water, and, placing a finger over one end, invert and hang it over the edge of the Apparatus or dish full of water, and remove the finger. Raise it until the water runs out in drops, and finally not at all. Experiment till you see how to make it run either slowly or rapidly at pleasure.



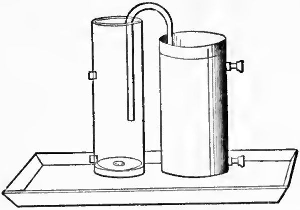
Exp. 57.



Exp. 58.

INFERENCES. 1. Infer the difference in conditions. 2. Test your statements by using the unequal-arm U-tube, to see if you gave the conditions correctly. 3. Explain carefully what starts the water running, and what keeps it running. 4. If there were no air in the room, would it run at all? 5. If you think it would, tell how and why. This instrument is called a siphon, and it has a great many forms. Experiment with any other you find in your set. Make one with your long rubber tube, and experiment with it in different

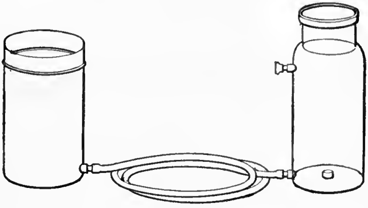
positions. 6. How many of the tubes in the "100 in 1 Apparatus" set, can you use as siphons?



Exp. 59.

Exp. 59. Use the same apparatus as in Exp. 58. with the addition of the tin, and, after the water has reached the same level in each dish, raise first one, then the other, and watch the changing direction of the flow.

Inferences. 1. Which, in each case, is the longer arm of the siphon? 2. The length of each arm of a siphon is the perpendicular distance between the highest point of water in it, and what other point or level?

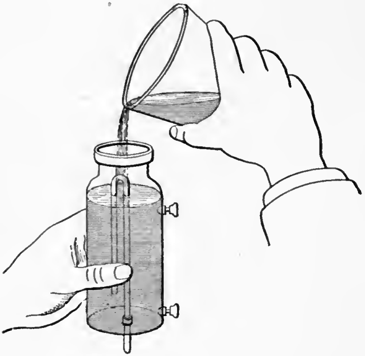


Exp. 60.

Exp. 60. Fill one dish with water, and as soon as it begins to run into the other, raise the centre of the rubber tube as high as possible above the dishes.

INFERENCES. 1. What starts the flow? 2. What keeps it going? 3. Does the force that keeps it running affect it when the tube lies on the table or hangs over the edge? 4. In which of the three cases would it flow just the same if there were no air in the room?

Exp. 61. Insert the end of the longer arm of U-tube into the bottom hole of the Apparatus till the bend is



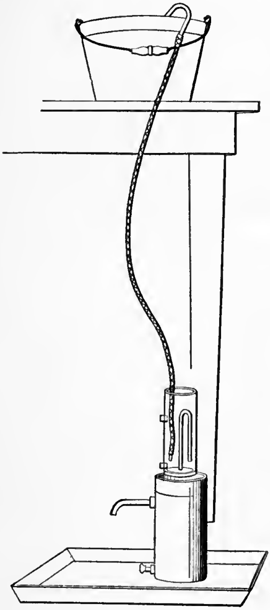
Exp. 61.

below the mouth, and fill the Apparatus with water. This is called a Tantalus cup.

INFERENCE.

Exp. 62. Fasten the Apparatus and tin can tightly together with the unequal-arm siphon and a half-inch piece of rubber tubing taken from the pressure-gage and used as packing for both. Arrange as illustrated, with your

finest jet-tube on the lower end of the rubber tube to supply a small but constant stream of water to the "Tantalus cup," and you will have an intermittent flow from the cup. Should the jet-tube be too large to allow the discharge from the cup to intermit, diminish the water-supply by pinching the tube at the right time.



Exp. 62.

INFERENCES. 1. How many siphons are there in this experiment? 2. In what essential respect do they agree, and in what do they differ?

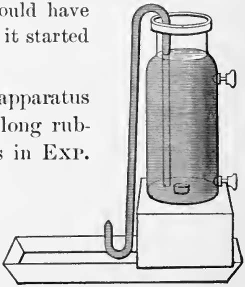
An intermittent spring is one that does not flow all the time, but has alternate periods of flow and rest. The periods of rest come generally after a long dry spell, and sometimes not till the dry spell has ended and it is again rainy weather. Fig. 10 illustrates the conditions of a hill from which there issued such a spring, until a railway was cut through it and the spring was destroyed. In the hill was a cavern seamed with numerous small

cracks through which ran the water that filled it. The water flowed out through a single arched opening.

Fig. 10.

INFERENCES. 1. Explain how the flow became intermittent under varying conditions of weather. 2. Under what conditions might a drought come and go without the flow of water ceasing? 3. If it stopped flowing, how much rain or melted snow would have to find its way into the cave before it started again?

Exp. 63. Instead of the apparatus shown in the cut, use your pail, long rubber tube, and a short jet-tube, as in EXP. **62**, to construct and operate a siphon fountain. Vary the height of the jet of water by raising and lowering the jet-tube.

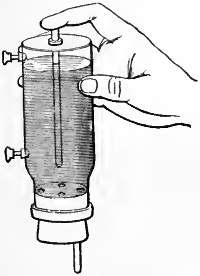


Exp. 63.

INFERENCE.

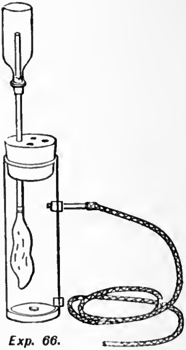
Exp. 64. Place a short tube in one hole of the stopper and a 6-inch tube in the bottom hole of the Apparatus. Fill the Apparatus with water, and insert the stopper. Place your finger over the end of the tube beneath the Apparatus, and invert. Use the bottle dropper as you did the tube in Exp. 53.

Inference.



Exp. 64.

Exp. 65.



Exp. 66.

Exp. 65. If the Apparatus and tube are full of water, and you uncap the upper jet-tube, how much water will run out? This is a good test of your previous work on air pressure. Answer first, then verify by experiment.

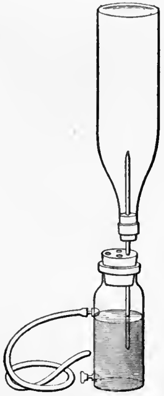
Inference.

Exp. 66. Place in any position, and suck air from the Apparatus.

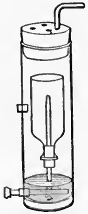
Inferences. 1. Distinguish between the force that fills the rubber bag in this case and in "how we breathe" (Exp. 46). 2. How is the air withdrawn from the Apparatus? 3. What forces it from the bottle into the rubber balloon?

Exp. 67. The same bottle used in the previous experiment, and to be used in the next, will answer for this also. However, the taller the bottle, the prettier the experiment. Suck air from the Apparatus, observing what is happening to the air in the bottle at the same time. Pinch the tube, rest your throat, and suck again till you remove as much as you can ; then let go the rubber tube.

INFERENCE. Explain each part of the experiment, that is, the operation of the fountain, and the process of preparing conditions necessary for its success.



Exp. 67.



Exp. 68.

Exp. 69.

Exp. 68. Fit a jet-tube tightly to the small bottle, and put it inside the Apparatus. Pour in a little water, cork tightly, and suck out the air.

. INFERENCE.

Exp. 69. With the short thick-walled rubber tube on the large end of the jet-tube, suck the air from the Appa-

ratus (or bottle and attachment No. 6); pinch the rubber while transferring the end in the mouth to a dish of water, then release it.

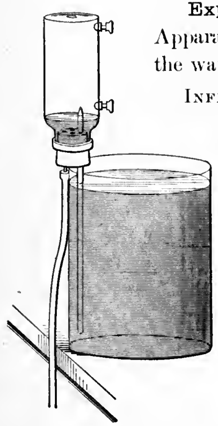
INFERENCES. 1. How much of the air did you get out? (After a little practice you can easily exhaust nine-tenths of it.) 2. Do you *draw* it out? 3. What forces it out?

Exp. 70. Fill the Apparatus or bottle with water, tightly insert the stopper with holes open, after which put a 6- or 8-inch tube through one hole, plug the others with shot. Try to suck out water.

INFERENCE. Why cannot you do so?

Exp. 71. With but little water in the Apparatus, and with the tube reaching into the water, try again.

INFERENCES. 1. Why can you get water now? 2. How does air differ from water as regards the cohesive force between its particles? 3. In place of the cohesive force, what kind of a force does air possess? 4. How does it act compared with cohesion? 5. Compare with discussion of EXP. **54**. See AUX. **17**.



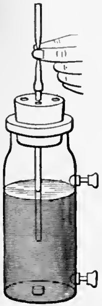
Exp. 72.

Exp. 72. With a little water in the Apparatus, insert in the stopper the longest jet-tube and a short glass tube connected with the long rubber tube, and hang them upon the edge of a jar or pail of water.

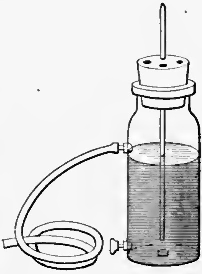
INFERENCE. Explain and name the fountain by use of the principles employed.

Exp. 73. Place the short heavy rubber tube a very short distance on the small end of long jet-tube reaching into water in the Apparatus or a large bottle. Blow as much air as possible into the Apparatus, pinch the rubber tube while removing it from the mouth, and pull it off the jet-tube.

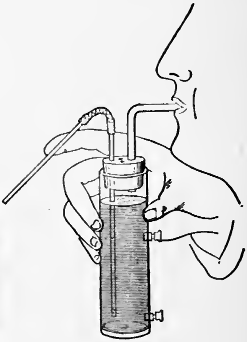
INFERENCE. What *two* properties of air not possessed by water does this experiment show ?



Exp. 73.



Exp. 74.



Exp. 75.

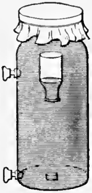
Exp. 74. Blow through the rubber tube, thereby making a miniature fire-engine. See AUXS. **18** and **19**.

Exp. 75. This is called in the laboratory a "blow-bottle" or "wash-bottle." It is used to supply a small stream or a few drops of water to a vessel, or to withdraw the same. Construct it as illustrated, fill with water, and use it for both purposes by filling and emptying one of your small bottles.

INFERENCE. Explain the principle in each method of using it.

Exp. 76. Connect the long rubber tube to a side hole of the Apparatus. Wet the stopper, and insert it not very tightly, then blow hard through the tube. See AUX. **20.**

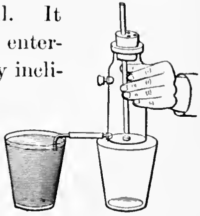
Exp. 77. Partly fill the small bottle — "bottle diver" — with water until it floats inverted, with the bottom just at the surface of water in dish. Transfer it to the Apparatus or large bottle *full* of water without changing the amount of water in the small bottle. Tie the sheet rubber over the mouth. Press on the sheet rubber enough to send the bottle diver to the bottom, then remove the pressure. If the small bottle is delicately balanced by having *exactly* enough water in it, the sheet rubber is not needed; use the palm of the hand instead.



Exp. 77.

INFERENCE. Explain every step of the experiment. See AUXS. **21** to **29.**

Exp. 78. A little care is necessary in order to get the tube *exactly* centred over the bottom hole, and near enough to it to work well. It should be as near as possible without entering the hole. To give the necessary inclination to the tube, crowd the rubber stopper in more on one side than the other; it is easier to use a common cork with a hole in the centre. The tumbler or bottle used instead should be quite full of water. Blow hard through the tube, and water as well as air is blown out.



Exp. 78.

INFERENCES. 1. What must be the condition of the air in the Apparatus before water can rise into it? See AUXS. **30** and **31**. 2. What produces that condition? 3. How?

Exp. 79. Blow hard through the tube held in a horizontal position, with wooden ball held an inch or more above the opening near the bend; let go the ball, and keep it floating in mid-air. After acquiring some skill with the tube in that position, incline it as shown in the picture, and see how much you can do so, still keeping the ball in the air. See AUXS. **32** and **33**.

Exp. 79.

INFERENCE.

SUPPLEMENTARY GRAMMAR-SCHOOL WORK.

QUANTITATIVE STUDY OF PRESSURE, COMPRESSIBILITY, AND EXPANSIBILITY OF AIR.

TO THE TEACHER.

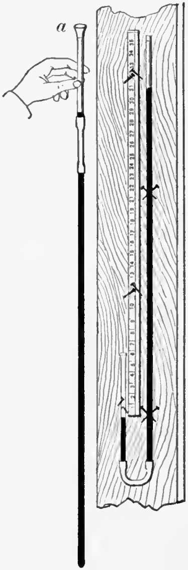
This quantitative work presupposes that the pupil has mastered the qualitative work preceding it, and that he has not only obtained the facts, but that it was done in the proper manner, so that he is able to think for himself, and to use the facts previously obtained as instruments of thought. These experiments, we know from experience, are none too hard for grammar-school pupils who have laid the proper foundation for them ; and the pupil's work on the first five, especially that on the fourth and fifth, will determine whether he is prepared to advance.

Exp. 80. Join the Apparatus, a glass connecting-tube, the long rubber tube, and a jet-tube. Hold it as illustrated. Fill the Apparatus with water, and when it begins to flow from the jet-tube insert the rubber stopper. If convenient, connect two rubber tubes, stand upon a table, step-ladder, or hall-stairs, and repeat the experiment.

Inferences. 1. Why cannot you determine with rubber tubes how high a column of water air-pressure will sustain ? 2. Could you determine this with a glass tube if it were long enough ?

Exp. 81. (This experiment should usually be done by the teacher.) Take the barometer from its permanent place against the wall or window-casing, and hold it as

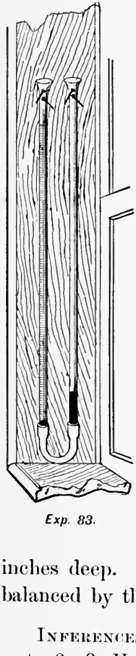
Exp. 80.



Exp. 81.

shown in "a." Call attention to the fact that the long glass and the short rubber tube are full of mercury, and that no air can enter the tubes except at the open end. Slowly invert the long tube, while the pupils watch the upper end of it.

INFERENCES. 1. Why has the mercury sunk in the long tube, and risen in the short one? 2. What is in the long tube above the mercury? 3. How much of the mercury is balanced by air-pressure? 4. How deep a sea of mercury would it take to press upon the earth just as much as the air presses? 5. If you should carry this barometer up a high mountain, and the difference in the length of the columns of mercury diminish one-half, how much of the air would you have passed above? 6. That much in depth or weight? 7. Why not the same amount in both depth and weight?



Exp. 83.

Exp. 82. Observe the length of the mercury column of the barometer, at least once a day, and make a record of it on a printed calendar or in a table of your own construction.

INFERENCES. 1. Infer as to the variation of air-pressure. 2. Can you discover any relation between air-pressure and the weather — fair or stormy? 3. Study a Signal Service weather-map in this connection.

Exp. 83. Pour mercury into the Apparatus until it stands in each tube one-half inch or more above the rubber connector. Pour water into one tube until it is 13.5 inches deep. Measure the height of the mercury column balanced by the water.

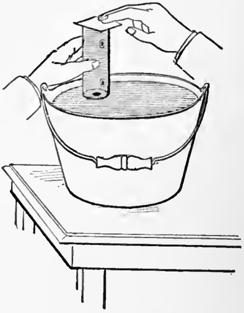
INFERENCES. 1. Mercury is how many times as heavy as water? 2. How high a column of water will air-pressure sustain when the difference in the mercury columns of a

barometer is 30 inches? 3. At the same time, what would be the greatest possible distance between the water in a well and the lower valve in a lifting-pump? 4. As a cubic inch of mercury weighs about half a pound, what is (to the nearest pound) the pressure of the air upon every square inch of the sea? 5. Why is it not the same upon every square inch of the land surface of the earth?

Review Inferences 11 and 12 to Exp. **16**, of first course (reprinted below), and make corrections for air-pressure when barometer stands at 30 inches.

"Exp. **16** — Inferences. 11. A cubical tin dish with bottom one foot square will hold 62.5 lbs. of water. If full, what is the pressure against one side of the dish? 12. What is the total water-pressure against the sides and bottom?" 3. How much of the outward is balanced by inward pressure? 4. What is the upward pressure of the water at its surface?

Exp. 84. (Exp. **51** of first course.) With the mouth and the bottom hole of the "100 in 1 Apparatus" open, sink it in a dish of water. Cover the mouth with a card, or the palm of your hand, and, holding it firmly in place, lift the Apparatus nearly out of the water.



Exp. 84.

Inferences. 1. Does the water press upwards against the card? 2. If so, which presses the harder, water underneath or air on top?

Note. — Of course an inverted tumbler or bottle will answer just as well as the Apparatus for this experiment.

Imagine that you have an Apparatus as many times the height of the mercury column in the barometer as mercury is times as heavy as water.

INFERENCES. 1. What is the height of your imaginary Apparatus? 2. What is the water-pressure against the under side of the card? 3. What is it against the bottom of the Apparatus? 4. How does it compare with outside air-pressure, .25, .50, .75 way from the bottom to the top? 5. How would the total water-pressure against the inside compare with the total air-pressure against the outside, if inside and outside surfaces were exactly equal? 6. Make the above comparisons with an Apparatus of the same height, open at the top and closed at the bottom. 7. If two water-towers should be built of equal strength throughout, with exactly the same conditions as the above imaginary pieces of Apparatus, — i. e., one open at the top and closed at the bottom, and the other closed at the top with the bottom open under water, — and each should leak soon after being filled with water, at or near which end, in which direction (inwards or outwards), and what substance, would each one leak? 8. Compare carefully in regard to both air- and water-pressure, a standpipe for city water-supply, and a pipe through which water passes from a deep well to the lower valve of a pump. 9. Explain now, if you did not then, why, when you used two or three tubes connected in EXP. 1, a part of your tube flattened? 10. Why cannot you pump water from a deep well through a rubber tube?

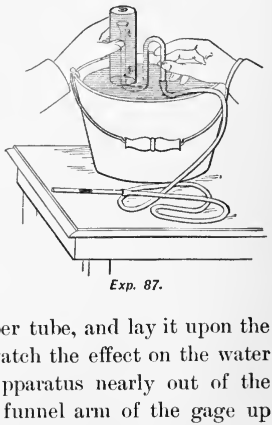
Exp. 85. (EXP. 37 of first course.) Fill with water a tumbler, or, better, a wide-mouthed bottle, cover with a card or disk of any material such as wood, tin, zinc, lead, or glass, or with a piece of cheese-cloth, silk veiling, or wire netting; then invert, holding it only by the side.

INFERENCES. 1. Do, or do not, the same conditions of pressure exist as in above apparatus closed at the top? 2. Can you hold a tumbler full of water so that either water-pressure from within or air-pressure from without shall be the greater? 3. If, when the tumbler is inverted, air-pressure holds up the water, of course *you do not;* does it seem as heavy then as when held right end up? 4. Explain why, if it does; and why not, if it does not.

Exp. 86. (EXP. **52** of first course.) Same as EXP. **84**, excepting that sheet rubber is tied over the mouth of the Apparatus.

NOTE. — A wide-mouthed bottle, the taller the better, with a hole in the bottom, or with the bottom broken off, will answer in place of Apparatus for this experiment, and also for EXP. **84**.

Exp. 87. Lower the Apparatus sidewise into a pail of water, and stand it inverted upon the bottom of the pail. Connect the long rubber tube at one end with the pressure-gage, and holding the gage horizontally, lower it into the pail till water reaches the second bend, then leave it held in place by the rubber tube bending over the edge of the pail. Nearly fill the 8-inch jet-tube with water, connect



Exp. 87.

it to the other end of the rubber tube, and lay it upon the table. Lower the gage, and watch the effect on the water in the jet-tube. Raise the Apparatus nearly out of the water, and carefully bring the funnel arm of the gage up

into it to the top, watching the effect in the jet-tube. If the effect is not exactly the reverse of that produced by lowering the gage, the experiment was not well done; perhaps the rubber tube was compressed, thus entirely changing the result. Our great teacher — NATURE — always answers the same questions the same way.

INFERENCES. 1. Do, or do not, your results in the last two experiments confirm your inferences in EXP. **84**? 2. Should they, or should they not?

Exp. 88. With the mercury at the same level in both tubes, measure the length of the column of air confined in the closed tube; this column should be exactly 3 inches long. Raise the open tube till the surface of the mercury in it is fifteen inches above that in the closed tube. Measure the same confined air, and place the result in Diagram 1, column 3, on the next line below figure 3. Raise the open tube till the difference in mercury-level is 30 inches. Measure the same air again, and place the result below the last. Return the open tube to its first position, then either lower it or raise the closed tube till the difference in mercury-level is first 7.5, then 15, and then 20 inches, each time measuring the confined air, and recording as before. In each part of the experiment imagine a line drawn horizontally across both tubes at the lower mercury surface. Of course the mercury below that line in either tube is balanced by the mercury below the line in the other tube. Now study to determine the amount of downward pressure at the level of that line in the open tube, using the pressure of the air upon the surface of the mercury (= about 15 pounds to the square inch) as the

DIAGRAM FOR EXPERIMENT 88.

AIR-PRESSURE WITH BAROMETER AT 30 INCHES THE UNIT OF ALL FORCES.

NO.	DIFFERENCE OF MERCURY-LEVEL.	LENGTH OF AIR-COLUMN IN TUBE.	FORCE ACTING DOWNWARD IN THE LEFT TUBE.	FORCE ACTING DOWNWARD IN THE RIGHT OR OPEN TUBE.
6	20 inches	inches	{ Expansive force = Weight of mercury = ________	= Pressure of air in open tube.
5	15 "	"	{ Expansive force = Weight of mercury = ________	= " "
4	7.5 "	"	{ Expansive force = Weight of mercury = ________	= " "
1	0 "	3 "	{ Expansive force of enclosed air = 1 ____ 1	= " "
2	15 "	"	" " = ________	= " " = Weight of mercury.
3	30 "	"	" " = ________	= Pressure of air. = Weight of mercury.

Diagram 1.

1 NO.	2 PRESSURE AGAINST ENCLOSED AIR.	3 EXPANSIVE FORCE OF ENCLOSED AIR.	4 DENSITY OF ENCLOSED AIR.	5 VOLUME OF ENCLOSED AIR.	
6					
5					
4					
1	1	1	1	1	
2					
3					

Diagram 2.

unit. Place the number representing the pressure at the left of the sign of equality on the proper line in the right-hand column, as has been done on line 1. If a part of the pressure is due to the weight of mercury, determine how much in the same unit (one air-pressure), and put it in the place indicated. Of course the total downward pressure at the level of that line must be the same (on the same amount of surface) in the closed tube as in the open tube. Determine first in each case how much of it is due to the weight of mercury, then to the expansive force of the enclosed air, and indicate each in its proper place, as on line 1. See if the sum of the two is, in each case, equal to air-pressure and weight of mercury in the open tube.

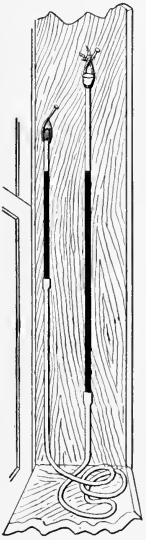

Exp. 88.

Diagram 2. Of course the enclosed air must in each case press down against the mercury with a force just equal to the upward pressure of the mercury against it. Now insert in column 2, of Diagram 2, the proper numbers to express in each case the pressure of the mercury against the enclosed air. Insert in column 3, numbers representing the resistant force, in 4 the density, and in 5 the volume of the same air; 1 represents the condition of each at the beginning of the experiment. Use these diagrams, and all others, only to help you to see and compare the facts in nature.

Inferences. Examine all your numbers, and think carefully what they represent, and see what comparisons you can make between pressure exerted upon confined air, and the expansive force, density, and volume of the air. Make a general statement, giving the results of your comparisons. Ask yourself and answer several questions, such as: 1. If pressure against a definite amount of confined air is doubled, how is each — its expansive force, density, and volume — affected? 2. If the volume of confined air is seen to increase (with no chance for other air to leak in), what must be true of its density, its expansive force, and of the pressure that is exerted against it? 3. What would you do to confined air to treble its density? and if this were done, how would its volume and its expansive force be affected? etc.

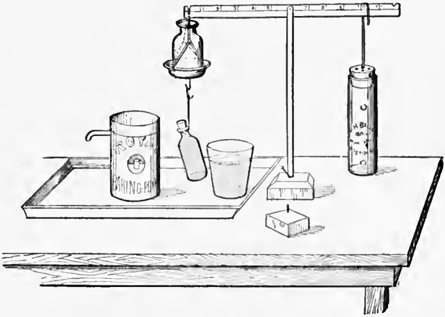
BUOYANCY — SINKING OBJECT.

Note. — Careless pupils will do better work by using both scale-pans for Exps. **89** and **90**, the same as for **91** and **92**, together with a small dish of *fine* shot for balancing material, handling it with a small tin spoon. With careful experimenters, however, the Apparatus, suspended with the copper wire made to slide somewhat snugly along the lever, is more satisfactory.

Exp. 89. Set up the Apparatus as shown in the cut, with the small bottle filled with water hanging within about half an inch of the pan. Carefully slide the Apparatus on right arm (or put shot into the scale-pan instead) till it balances the bottles, with the lever as nearly horizontal as your eye can detect. Lift the Apparatus by the upright piece, and set it down with the bottle hanging in the tumbler of water.

Inferences. 1. Why does it not balance with the beam of the scales horizontal as at first? Lift the end of the right

arm of the lever. 2. What new force opposes you, and what causes it? 3. You exert a force just equal to the weight of what? If you did the first twenty-three experiments properly, you can answer the last questions correctly. See note to Exp. 23. Restore the Apparatus to the first position. Pour water into the tin can till some runs out. Remove the tumbler. Seize hold of the scales-beam with your right hand at the centre, and hold it horizontal while removing the wide-mouthed bottle and placing it under the water-spout. Then lift the



Exp. 89.

Apparatus, and lower the bottle into the tin can, and when the water ceases to run, return the wide-mouthed bottle with its contents to its scale-pan, and see if it then balances with the bottle entirely under water. If it does not, try again. Perhaps the string is not of correct length, or you may have changed the point of suspension of the Apparatus, or perhaps a certain force about which you have previously learned (4. What is it?) interfered with the discharge of water at one time more than at the other, hence you have not, by a few drops, the correct amount of water in the wide-mouthed bottle.

5. Why does an object weigh less in water than in air? 6. To what is its loss of weight exactly equal? 7. Why do the scales balance with the bottle under water now, when they did not with the bottle hanging in the tumbler of water? 8. Is the buoyancy force exerted in both instances? 9. Is it always exerted upon an object immersed in water? 10. Which of the two fundamental facts about water-pressure accounts for it? 11. Does the amount of buoyancy depend upon the weight, size, or shape of immersed object? If necessary, experiment to determine; but if you find it necessary, previous work has not been sufficiently thorough. 12. Does any *fluid* except water exert this force upon immersed objects? 13. What is a fluid? 14. Which weighs the more (is actually the heavier), a pound of gold or a pound of feathers; a block of wood in one of your scale-pans or the shot, iron, or sand which exactly balances it in the other? 15. Is your own weight as indicated by accurate scales absolutely correct? 16. What correction does it need?

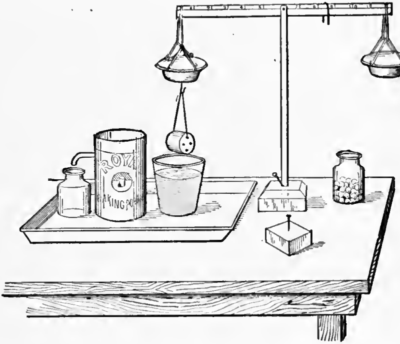
BUOYANCY — FLOATING OBJECT.

Exp. 90. Use the block suspended by a pin stuck into the centre of one of the larger sides, and proceed as in Exp. **89**.

Inferences. 1. State the relation between the weight of the block and the weight of the displaced water. 2. Make a general statement that will apply to any floating object, even to an ocean steamer or a man-of-war. 3. Explain the relation of buoyancy to the weight of an object that floats and of an object that sinks. 4. As a given quantity of ocean water is heavier than the same quantity of river water, what is the effect upon a boat floating from a river into the ocean? 5. Why is it easier to swim in salt water than in fresh?

SPECIFIC GRAVITY—SINKING OBJECT.

Exp. 91. Bring the scales to a perfect balance by means of the wire rider, which should pinch the beam tightly enough to be held firmly in place. Hang the rubber stopper to the hook, and balance with "Single F"



Exp. 91.

shot. Count the shot. Bring a dish of water up under the stopper till it is entirely covered, tip and shake the stopper to get all the air out of the holes, then remove shot till it balances, or as nearly so as possible with that size shot. Count the shot again.

NOTE. — The scales are delicate enough to do much finer work. If this is desired, obtain a piece of sheet lead, and cut it into narrow strips of equal width throughout. Balance a strip with "Single F" shot, and cut it into as many rectangular pieces as it equals shot in weight. Halve and quarter the pieces, and give each pupil a piece of each size. It is also desirable to have three or four weights each five or ten times

as heavy as the shot. Strips of sheet lead easily cut with a knife or scissors to the desired weight, rolled, flattened, and marked v. or x., are the neatest and easiest made. The button-shaped lead dress-weights, or even bullets, may be cut down to "ten-shot weights." New nickel five-cent pieces may be used, in which every cent equals a shot in weight.

INFERENCES. 1. Which is the heavier, the stopper or the same bulk of water? 2. What is their relative weight as nearly as you can tell from this experiment? 3. Is it necessary to balance the same bulk of water with shot? In the same way experiment with various substances, such as glass, iron, brass, lead, coal, stone, etc., and make a table showing the weight of each compared with water. For glass use a small bottle left open so that water may enter, as it then becomes merely a piece of glass. An iron nut and a short piece of lead pipe are usually easily obtained. 4. Each result gives you (very nearly at least) what is called the Specific Gravity of — what? 5. Is it of the object, or of the material of which the object is made? 6. Would your results have been the same had you used larger or smaller objects of the same material? If you are not sure, ask Nature. 7. Does Specific Gravity mean the actual weight? 8. Do you have to know the actual weight of a substance either in air or in water, in order to find its Specific Gravity? 9. What does Specific Gravity mean?

SPECIFIC GRAVITY — FLOATING OBJECT.

Exp. 92. Find how many shot it takes to balance the hard-wood block. Stick a pin into the block, and by means of your tin dish with spout find its bulk of water, and then balance this with shot.

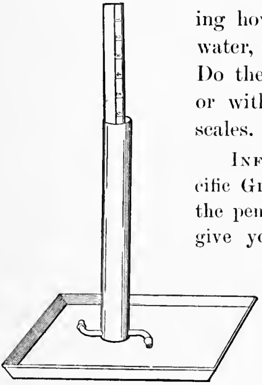
INFERENCES. 1. What is the Specific Gravity of the wood? 2. If the Specific Gravity of any substance is

greater than one, what will it do when placed on water, and what if it is less than one?

Exp. 93. Place a small piece of soft-wood board (base of scales will answer) on water, and determine as nearly as you can by looking at it its Specific Gravity.

INFERENCES. 1. If it floats with just one-half above the surface of the water, what is its Specific Gravity? 2. What if two-thirds are above water? 3. What if one-third?

Exp. 94. Fill apparatus No. 5 of first course with water. Hold it upright in a dish to catch the overflow. Lower a foot rule into it, and by seeing how much it projects above the water, calculate its Specific Gravity. Do the same with a graphite pencil, or with the upright piece of your scales.



Exp. 94.

INFERENCES. 1. What is the Specific Gravity of the rule? 2. What of the pencil? 3. Does this experiment give you the Specific Gravity of the kind of wood of which the pencil is made? 4. What does it give you? 5. If you should perform EXP. 92 with a corked bottle of water and air, of what would you get the Specific Gravity? 6. Would the Specific Gravity of all bottles of water and air be the same? 7. Would it be the same for all pencils made of the same kind of wood and graphite? 8. As glass is a compound of many substances, used in many different proportions, would you expect all kinds of glass to have exactly the same Specific Gravity?

Exp. 95. First, find how many shot will balance the small bottle; second, how many when filled with water; and third, how many when filled with kerosene oil; and find the Specific Gravity of the oil. If you have mercury enough, find its Specific Gravity the same way, and see if it agrees with results obtained in Exp. **83**. If you have not enough mercury, choose some other liquid, such as strong brine, which you can easily make by dissolving in water as much salt as possible.

Inference. Give the Specific Gravity of each.

Exp. 96. (If convenient.) Find the Specific Gravity of kerosene oil with the same apparatus used with water and mercury in Exp. **83**.

Inference. How nearly does it agree with results found in Exp. **95**?

SPECIFIC GRAVITY OF LIQUIDS BY BUOYANCY.

Exp. 97. With your balancing apparatus find the Specific Gravity of brine and of oil, or of alcohol, by finding the buoyancy of each, and comparing it with that of water.

Inferences. 1. Give the Specific Gravity of each, and compare with that found by the other method. 2. Could you find the Specific Gravity of mercury in this way? 3. In general of what liquids could you?

SPECIFIC GRAVITY OF LIGHT SOLIDS BY MEANS OF A SINKER.

Exp. 98. With your balancing apparatus, and by work similar to that which you have already done, find the Spe-

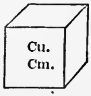
cific Gravity of the hard-wood block by tying to it a piece of lead or iron sufficient to make it sink in water. Make balancings of the block and of the sinker separately and together, both in air and as far as possible in water. Set down the value of each, and make use of them all to think with, and such as you need in figuring out the result. Do all the thinking necessary yourself; for, if you are told just what to do, you might as well not use this method at all.

DENSITY.

Thus far you have not needed to do any weighing; but for the rest of the experiments you must know the weight of your shot, or at least know how much water will weigh the same amount. If you should take 100 "Single F" shot and just water enough to balance them, and measure the water in cubic inches, and divide by 100, you would, of course, get the amount of water equal in weight to one shot. This we have done for you, and found that a cube of water .4 of an inch on each edge equals in weight a "Single F" shot. Now, it so happens that .4 of an inch (called a centimetre) is the unit of measurement used in all laboratories and for all scientific work, both in Europe and America; and the weight of a cube of cold water of that size is the unit of weight, and is called a gram. This much of the Metric System you need in order to understand the subjects that follow. Hence you will now call the "Single F" shots "gram weights." You will also familiarize yourself with the centimetre, or unit of length. Compare it with the inch, then compare 30 cms. with the foot. Hereafter, in this work at least,

make all your measurements in centimetres and decimals of the centimetre. As you will find it more convenient to have some weights heavier than one gram, obtain some new nickel 5-cent pieces. They weigh exactly 5 grams each. Or better, make some 5- and 10-gram weights of sheet lead, or of something else, as directed in note to Exp. **91**.

Note. — The true unit of the Metric System is the metre, which is equal to 39.37 inches; but just as we divide our unit of value — the dollar — by 100 to get a smaller unit, which we call a cent, so the metre is divided by 100, and the smaller unit is called a centimetre. This is, as you see, not quite .4 inches; but it is nearer to it than you can possibly measure or even distinguish without a microscope. The gram is, however, the true unit of weight, and is obtained by taking a cubic centimetre of pure water at the temperature when it has the greatest density, which is very near the freezing point.



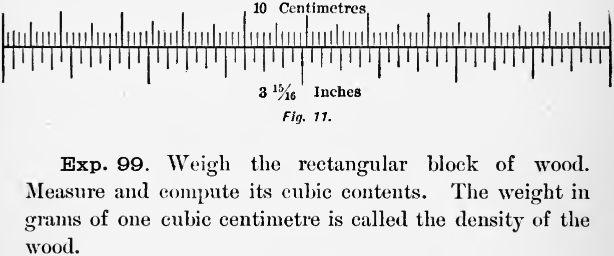


Fig. 11.

Exp. 99. Weigh the rectangular block of wood. Measure and compute its cubic contents. The weight in grams of one cubic centimetre is called the density of the wood.

Inferences. 1. What is the density of the block? 2. How does density differ from weight? 3. How does the density of one cubic centimetre of anything differ from its weight? 4. What is the density of cold water? 5. How does density differ from Specific Gravity?

Exp. Auxiliary to 99. If convenient, obtain some small rectangular blocks of different kinds of wood, and find the density of each.

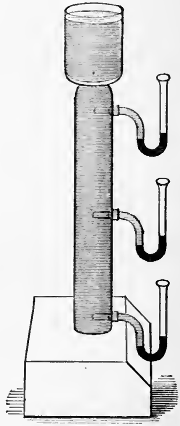
CUBIC CONTENTS BY WEIGHING.

Exp. 100. Find by weighing, both in air and in water, the number of cubic centimetres of rubber in your stopper, also of glass in one of your bottles, and of stone in some small irregular piece; or use other convenient objects.

Exp. 101. If you conquered Exp. **98**, find by weighing the cubic contents of a piece of wood, then by measuring, and see how nearly your results agree. Invent a bath-tub by means of which you could (if you constructed it) determine your exact size in cubic centimetres.

AUXILIARY APPARATUS AND EXPERIMENTS.

Auxiliary 1. This apparatus is more easily made with a tin tube than with a lamp chimney. Obtain a tube of any size or length; a piece of speaking-tube about 12 inches long will answer. Cork the lower end, and stick it in a hole bored in a block of wood. The latter serves as a stand. With an awl, or a sharp nail, punch three holes equally distant from each other, as in the illustration. Enlarge them with a rat-tail file, twisting it, and pushing the edge of the tin inwards, so as to make a lip or "burr." Make the holes equal in size to those in the "100 in 1 Apparatus."



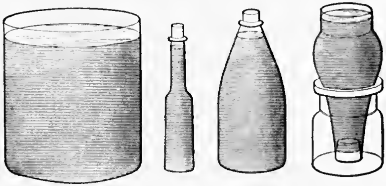
Aux. 1

For showing steady side pressure and its *exact law*, insert the U-tubes with bends each half full of mercury; then fill the tube with water, and observe not only the general effect upon the mercury, but measure the amount raised in each tube, and compare with corresponding depths of water.

Note. — To avoid confining the air in the tubes, pour in water until it runs into first tube, then carefully pour a little mercury into

tube funnel. Treat the second tube the same way, then pour more mercury into first if necessary, etc. To make this experiment of some aid to those not provided with the apparatus, we have violated our general rule, which is to show the apparatus in condition for the experiment, and not during it. In this case, we have shown it in progress, as the pupil should, whenever he makes a drawing to illustrate an experiment.

CAUTION. — When handling mercury, be careful not to allow it to come in contact with a gold ring; for the two metals will amalgamate, giving the ring the appearance of silver. Should such an accident happen, heating the ring *cautiously* will drive off the mercury, but the gold will need reburnishing.



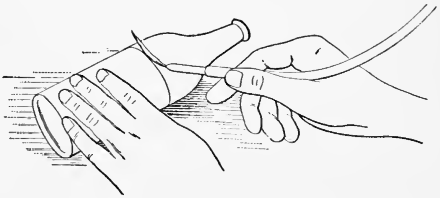
Aux. 2.

Aux. 2. Though most pupils see the principle in Exp. 16 without extra dishes, better have two additional pieces, — a beer-bottle and a lamp-chimney or tin funnel, the latter corked, and standing in a bottle. Being needed but once, and for only half a minute, one set will do for a class if placed where the pupils can use it in turn; each using his own pressure-gage if the work is all done at school, all with the same gage if regular experiments are done at home and only the auxiliaries at school. A very neat funnel-dish is made by cutting a beer-bottle, corking, and standing the neck part inverted in the lower.

EASY METHOD OF CUTTING GLASS BOTTLES.

Bottles are easily cut with a *fine* jet of burning-gas as follows: —

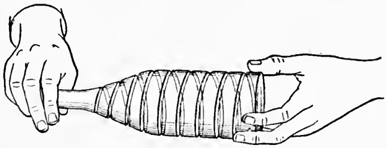
Scratch the bottle with a file along the edge of a strip of paper, tied around it for a guide. Remove the paper, and rolling the bottle, heat it along the scratch to a little distance ahead before the crack starts, or the latter may leave the mark. With thin glass, the crack will follow the gas-jet quite steadily without much heating



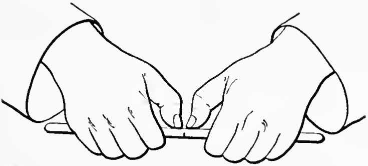
ahead; but thick glass cracks by "fits and starts." After some practice you can dispense with the scratch, except an inch or two where the crack is to be started. Sharp edges are smoothed with a wet file. A "half-round" file, one that is flat on one side and curved on the other, is best for this purpose, especially for the inner edge. Thin bottles may be cut with a flat-wick oil-lamp; but the line must be scratched entirely around, and even then the glass will not always crack where desired.

With little practice, bottles may be cut into spirals from end to end, after which they can be stretched considerably without breaking; when released, the glass will

resume its original length with a sharp click, showing its great elasticity. Test-tubes, lamp-chimneys, thin glass tumblers, and beakers are very easily spiraled.

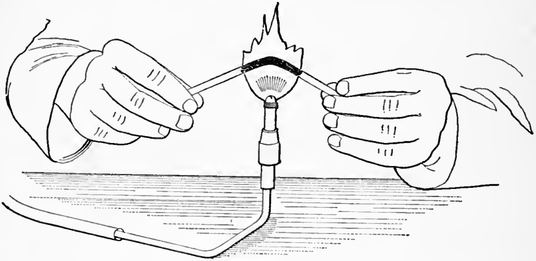


The latter the author has so cut as to be stretched to twice their original length. The smaller part of a chimney, like the one used for Aux. 1, the author cut into a spiral of 60 coils within a length of 8 inches. The diameter of the chimney was $1\frac{1}{4}$ inches. If you can estimate the present length of that 8-inch piece of glass, you will find that it is more than three times that of your height.

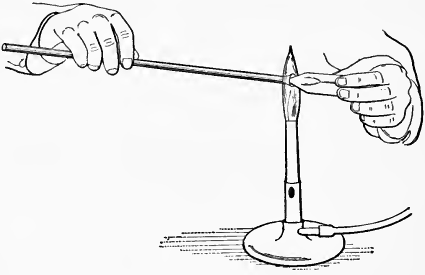


To break the tubing squarely, scratch it with the file, then hold it with the thumbs opposite the scratch, and break as you would a twig. The sharp edges are easily removed by means of a file; they may also be melted smooth in the Bunsen burner. To close the end, or to partly close it so that it may be used as a jet, hold it

in the hottest part of the Bunsen blaze, and keep turning it till the hole is small enough. To bend it, use a common gas-jet, not very large, and turn it while heating.

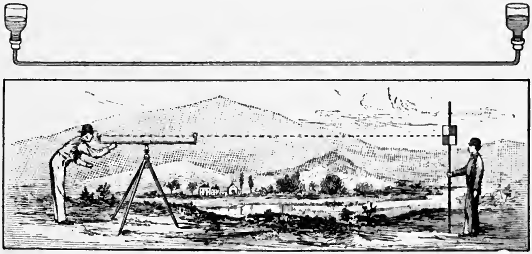


A little practice will enable you to do it neatly. The cut below shows how to make a small funnel from a glass tube, by using the Bunsen burner and a piece of charcoal sharpened like a pencil.



If not supplied with gas, you can shape *thin* glass tubing with an alcohol or a common flat-wick oil-lamp; but

it is very difficult work. Skilful glass-blowers can work with crude apparatus and poor materials, but pupils not accustomed to the manipulation of glass require the best of appliances. Do not try to hurry your work. When the glass begins to yield under the action of the heat, do not bend or shape it too rapidly. Unless necessary, do not bend a tube at too sharp an angle. In the above cut, the tube is bent at a sharper angle than is usually desired.

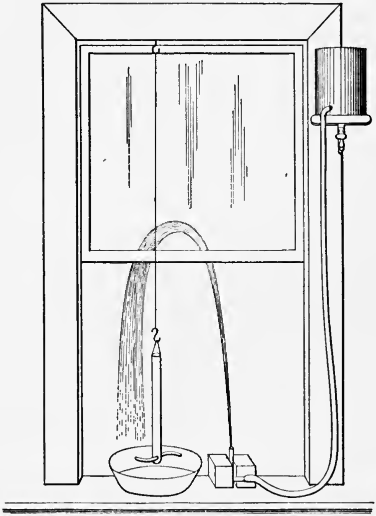


Aux. 3.

Aux. 3 shows a water-level made of two small bottles with their bottoms cut off, two corks, and a piece of glass tubing; it shows also how the level is mounted upon a tripod stand, and is used for getting the difference in level — or height above the sea — between two places.

Aux. 4. A fine auxiliary to Exp. 19 may be performed by placing a large tin can or pail on a high shelf near an open window, out of which the fountain can play. (To make a hole, see AUX. 1.) If not well supplied with rubber tubing, connect two from pupils' sets by means of a short glass tube, and insert the elbow jet-

tube, held in position by two blocks; or make one that will stand alone by bending a long piece of tubing twice, each elbow being at right angles to the other. (See stand for gas-jet in glass-bending picture above.)



Auxs. 4 and 5.

If you have gas, a great many pieces of very valuable apparatus may be easily made of soft glass tubing obtained at drug-stores, or purchased by the pound of school-supply dealers. Do not get the cheap, thin tubing; it breaks easily, and is very difficult to work. The only tools absolutely needed are a three-cornered file, a com-

mon gas flame, and a Bunsen burner, or the recently invented Bunsen blast alcohol lamp, sold by the L. E. Knott App. Company of Boston, and Eimer & Amend of New York.

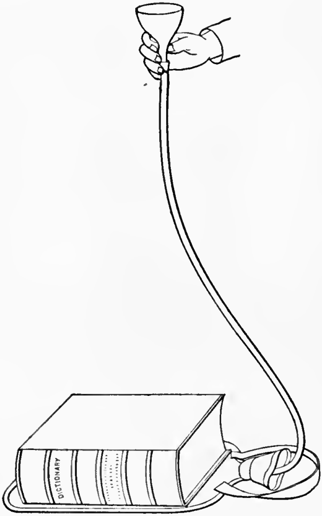
Aux. 5. (See cut above.) Exps. 20 and 21 are very pretty performed with a tall bottle. A quart ink- or wine-bottle does very well; a hole is much more easily made with a file in the edge than in the side of a bottle, and does just as well for these experiments. Still better and cheaper is a tin tube a foot or more long, corked at the bottom, and provided with a wire bail. Make the holes just above the cork, and insert tubes from the pupils' sets. If the class is large, it is better to have a piece for each experiment, and but one piece in a window, to which pupils go in turn to inspect it. Exp. 21 may be done in a variety of ways, thus: with both tubes horizontal in a large tin pan to catch the water; with the pan nearly full of water, the tubes submerged; with one tube horizontal, the other at any angle; with both tubes at different angles, imitating a lawn fountain.

No other auxiliary apparatus is worth so much in proportion to its cost as this; while performing Exp. 21, Aux. apparatus 4 may be combined with Aux. apparatus 5 by holding its jet-tube so that it will play into the top of it, thus prolonging the experiment.

Aux. 6. Procure a three or four quart hot-water bag.[1] Attach to it several feet of rubber tubing by means of a

[1] A two-quart bag costs from eighty cents to one dollar, according to the quality. A three-quart bag, which is a much better size for the experiment, costs about twenty-five cents more.

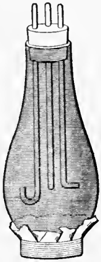
perforated cork and a short piece of glass tube. Place the bag upon the floor with a piece of board over it, on which stand, or place heavy weights; then pour water into the funnel at the end of the tube.



Aux. 6.

NOTE. — To make a funnel: if gas is available with which to cut glass, use the top of a bottle. With a rat-tail file make a hole in a cork that fits tightly, and insert one of the short glass tubes. Or take the pressed tin cover of a baking-powder can, and make a hole in the centre (see AUX. 1), pushing the tin outward, and fit glass tube to it with a a short piece of rubber tube.

Aux. 7. A fine auxiliary piece may be made by tying sheet rubber over the large end of a lamp-chimney. Fill the latter with water, and insert the stopper or a cork with tubes, as illustrated, and press on the rubber.



Aux. 7.

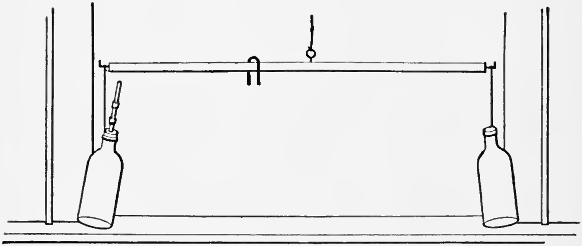
Aux. 8.

Aux. 8. (Study this figure, if not provided with the apparatus.) Connect a tube with piston to two others of the same size, as illustrated. With the water at equal depth in each, insert the piston in the middle one, and transfer the water to the other two.

Inference. How much pressure on the surface of the water in each will balance one unit on the surface of water in middle tube? Does the amount of pressure transferred to each side tube bear the same relation to that on the piston, as the amount of water transferred bears to that at first in the middle tube? What things are in the same relation to each other as applied and transmitted pressure? Did you make them so in inferences to Exp. 29?

Aux. 9. The rubber bulb of an atomizer, found at drug or rubber stores, makes a valuable addition to your apparatus, increasing the beauty and instructiveness of several experiments in air. Attach it to the rubber tube in Exp. 34, and it represents the pump on the deck of a wrecking-vessel, pumping air down to the workmen in a diving-bell.

Aux. 10. Even if you are not provided with an air-pump and delicate scales, it is not necessary to take for



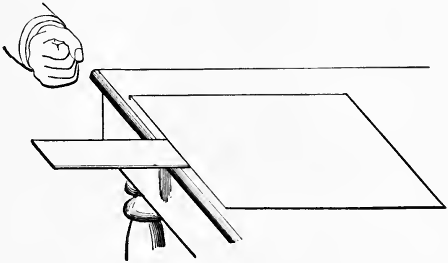
Aux. 10.

granted that air has weight. If you know how to suck, the following apparatus will show it clearly; and if you do not, you should practise until you do, for kind Nature has given you a pump good enough for any necessary experiment with air, even that of finding its exact weight if you are provided with delicate scales.

Suspend in the window a metre rod or yard-stick by a screw-hook or eye, in the centre. Drive a tack into each end, on which hang quart or larger bottles, one being

tightly fitted with a stopper, glass tube, and rubber tube with plug in end. Then pour shot, sand, or water into the open bottle until it balances the other, with bottoms just above the window-sill. A wire rider easily slid along the stick will enable you to get an exact balance. Suck all the air you can from the plugged bottle, resting several times, and replace plug.

INFERENCE. Why does the other bottle now rest upon the window-sill?



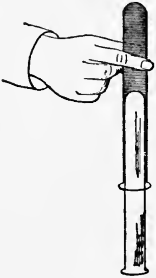
Aux. 11.

Aux. 11. Place a strip of *thin* board about two feet long on the table, with half its length projecting over the edge. Over the portion on the table lay smoothly several thicknesses of newspaper, full-page size. Strike the projecting end as hard a blow as you can; and if the blow is not followed by a push, you cannot knock the board off the table.

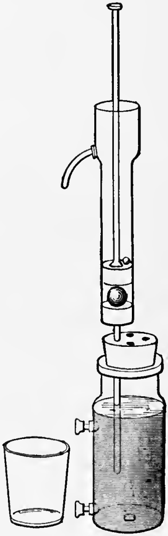
INFERENCE.

Aux. 12. Half fill the larger test-tube with water, and place the smaller one in it, the bottom touching the water. Taking hold of the larger one, invert them. If they are of correct relative size, the smaller will not fall out, but will rise inside the larger to the top.

INFERENCE. Why?



Aux. 12.



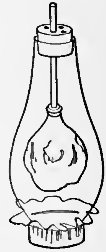
Aux. 13.

Aux. 13. A fine "suction" or lifting pump is easily made with a straight lamp-chimney. A marble and a large shot make the best and most interesting as well as the cheapest valves. The shot will rise an inch or two with the water when the piston is pushed rapidly down, and fall back, perhaps not over the hole; but when the piston starts upward, it gets into place instantly, making a very interesting experiment in itself. The piston should be

made of a rubber stopper with two holes, and should work very loosely, — in fact, it should not pump water without first being primed; then it works so easily that there is no danger of breaking anything. If made of wood, the piston-rod is easily pinned into one hole of the stopper; if of glass rod, heat it in the Bunsen lamp till soft, then crowd the ends to produce the bulge which keeps the stopper from slipping up; and by heating the end, and pressing it against something hard, a knob is made upon the end which can be forced easily through the hole in rubber stopper. Treat the upper end in the same way, and insert the piston from below. It should go in tightly at the end, which is generally a little smaller than the rest of the chimney. The lower stopper may be either rubber or cork, and the tube should not reach quite through it. If cork is used, make the hole from the small end so that its edges may not be torn, in which case the valve is imperfect. If you are not an expert in digging holes in glass, though it is easily done, the spout may be omitted, and the water allowed to run over the top. With the spout, however, the experiment is much more striking. Fill the Apparatus, or a bottle, with water, insert the pump-tube through the stopper, and plug the other holes. Work the piston up and down.

INFERENCES. 1. What happens? 2. Why do you not pump water now? 3. Remove one plug from the stopper, work the piston-rod, and explain every step of the experiment. 4. Could you pump water from any cistern that was air-tight? 5. Is it proper to say that the water is "sucked up," or to call a pump a "suction" pump? 6. What forces it up? 7. What produces the necessary conditions?

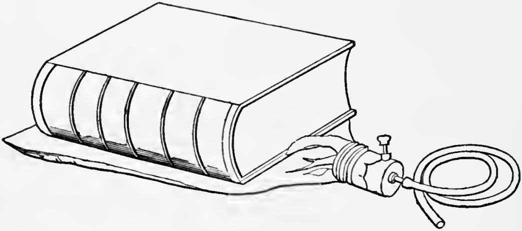
Aux. 14. A lamp-chimney makes a fine piece of "how we breathe" apparatus, and, with a long jet-tube, can be used for a "vacuum fountain."



Aux. 14.

Aux. 15. Fasten the long rubber tube to a hot-water bag (see AUX. 6), place weights of 50 or 100 pounds upon the bag, and blow through the tube. If the bag is large enough, you can sit upon it, and raise yourself with your own breath. For raising a large dictionary, or even a stack of them, a tight paper bag will answer; but it is very difficult to get it fastened air-tight around the tube. To do so, connect them by means of the Apparatus, around open end of which the mouth of bag is tightly fastened.

This experiment is sometimes published as a trick, and is called "The Power of the Breath." But the "power

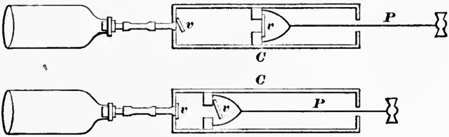


Aux. 15.

of the breath" is only about an ounce. With a properly constructed apparatus, however, a man can, with his breath, lift an ox. *Compare this principle with that of the water-press, Exp.* 30.

Aux. 16. Place a large sponge in a plate half filled with water. Note what takes place. With a few drops of ink or bluing, color a little water in a shallow dish, and stand a lump of sugar in it. Note the effect. Stand a piece of cane, rattan, or blackboard crayon, in a little turpentine or kerosene oil, and after an hour or two, according to the length of the piece used, hold a lighted match to the upper end.

INFERENCE. Explain the use of blotting-paper, candle- and lamp-wicks; and mention any other similar cases you can think of.

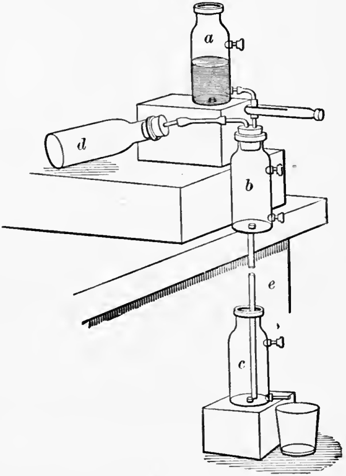


Aux. 17. The diagrams above represent a simple form of the air-pump, used to suck or "exhaust" a part of the air from a bottle. C is a cylinder in which works the piston P; v, v, are valves, or little doors, opening one way only.

INFERENCES. 1. Explain its action. When the piston is being pushed in, are the valves open or shut? Are they open or closed when the piston is being pulled out? Tell about each one in each case. 2. Does the force applied by the hand open the valves? What forces the air out of the bottle when the lower valve is open, and what opens it?

A mercury air-pump may be constructed with parts of three pupils' sets of apparatus. With this pump, *nearly all*

the air may be taken from a bottle. The apparatus itself is very cheap; but its use requires considerable mercury (none of which need be wasted, however), time, and attention. It is well worth constructing, if only for the purpose of studying its operation. If provided with a retort-stand



Aux. 17.

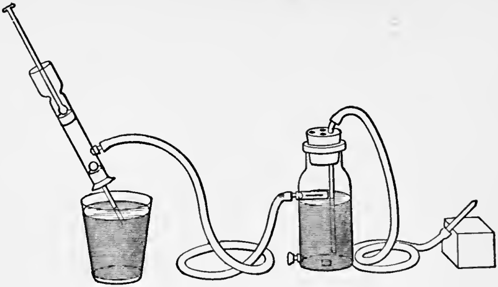
and a glass funnel, they may be used instead of Apparatus *a* and its supporting blocks. A screw-clamp for regulating the flow of mercury is better than the clothespin. In place of Apparatus *b*, one may use a small inverted bottle with the bottom cut off. A single tube (represented as broken) reaches from *b* to *c*. If the pump is used for practical purposes, and a nearly perfect vacuum is desired, this tube

should be about two and a half feet long, with a thicker wall and smaller hole than those commonly used. If used only for the purpose of study, two or three pieces well connected with short pieces of rubber tubing will answer very well. If a small amount of mercury is used, the experimenter is kept busy pouring it back into *a*. Two tumblers should be used; then, by tipping *c* a little to empty it, time enough during which there is no flow from it is obtained in which to change dishes. If the glass tubes between *b* and *d* do not nearly or quite touch each other, the rubber tube will be compressed (as shown in picture) so much as to prevent getting a free flow of the air from *d*. If they do touch, by keeping the rubber attached to *d*, with a little care they can be disconnected without allowing any air to enter. In order to secure the largest number of observations, tube *e*, in which they are made, should be a long one.

Aux. 18. With Exp. 74 use the atomizer bulb. It will throw a stream of water to a considerable distance,— fifteen or twenty feet.

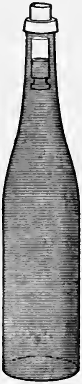
Aux. 19 illustrates the principle of the force-pump and the fire-engine. The piston must fit closely; hence the one used in the lifting-pump, the hole plugged, will not answer. The slit-tube valve was used in "How we pump water," Exp. 45. The larger the bottle used for the air and water chamber, the better.

INFERENCES. 1. Explain its operation. 2. Why is a large bottle better for an air chamber than a small one? 3. Why do you get a continuous stream? 4. Is the discharge into the bottle continuous?



Aux. 19.

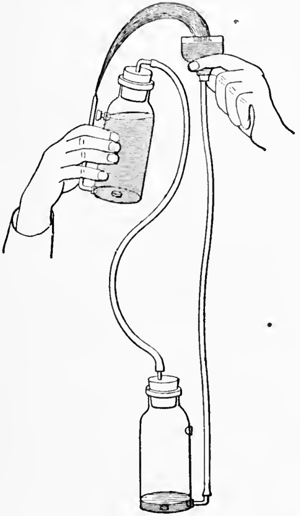
Aux. 20. Use an atomizer bulb, and, with the stopper wet and tightly inserted, pump air into the bottle until the stopper flies out. It will be expelled with considerable force, perhaps to the height of the ceiling. Observe the cloud of mist that frequently appears within the bottle after the explosion. If it does not appear at first, try it again on succeeding days to see if you can learn the condition of the atmosphere necessary to produce it; keep your record for future use.



Aux. 21.

Aux. 21. Get a tall bottle of any shape; fit a cork to it; fill it with water, and, after the small vial has been inserted, cork it. The small bottle is a "diver." If the latter contain just enough water, on tightening the cork a very little it will go down; on loosening the cork it will come up. If desired, a small image may be cut out of

tin, or any sheet metal, and hung to the neck of diver, making a water-balloon. To transfer the diver to the large bottle with small mouth, fill the bottle, then, after the proper amount of water in the vial has been found by experiment, place a bit of paper under the mouth of the diver and easily transfer it; then remove the paper. With care and a steady hand you can remove it without the paper, and without losing any water from it. (The bottle diver will be used again in studying the effect of heat on fluids.)



Aux. 22.

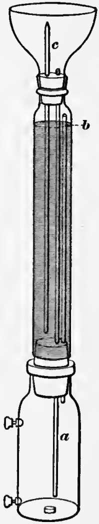
Aux. 22. As this experiment requires parts of apparatus from two sets, and assistance in starting it, two pupils had better work together. One should hold the funnel and bottle full of water as illustrated, the other pours water into the funnel to start it.

INFERENCE.

Aux. 23. Arrange three Apparatuses as illustrated, and blow through the open bent tube to start it. Vary the height of the fountain-piece, and notice the effect

upon the fountain. Try the same with the "fountain-head," the bottle in which you blew.

Aux. 23.



Aux. 24.

INFERENCE. Explain each step of the experiment, and be sure to tell what variations affect the height to which water rises, and what the length of stream after the water leaves the jet-tube.

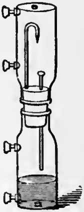
Aux. 24. This is a very striking and easily made form of Hero's Fountain, in which a jet of water rises

higher than its source. The upper part is the top of a large bottle; the central piece is the longer part of a lamp-chimney, like the one used in Aux. 1; the lower part is the Apparatus. The lamp-chimney is easily cut at the narrow place by the aid of a triangular file and the gas glass-cutter. All the glass tubes are open at both ends; *c* being a jet-tube passing through the upper stopper, and nearly reaching the lower. Two corks — or, better, rubber stoppers — may be used where one is illustrated, if the same one does not fit both glass pieces tightly enough. For the bottom piece, a large, heavy bottle is preferable to the Apparatus. This apparatus may be made with one piece less of glass, by using the long neck and a part of the body of a wine-bottle, together with two rubber stoppers, thus dispensing with the lamp-chimney; made in this manner, however, it is a short-lived fountain, the reservoir being much too small. Of course, if well made, this apparatus never needs taking apart; for, by inverting it, the reservoir is filled, and the surplus of water in the bottle is discharged, through the jet-tube. If the tubes do not discharge freely, a little careful shaking of the apparatus will make them do so.

Inference. Explain every step, both of the working of the fountain and the process of refilling the reservoir.

Aux. 25. This is an intermittent fountain, in which the water rises in spurts higher than its source, some of it passing several times from one bottle to the other before the action finally ceases. If the apparatus be carefully constructed, the water strikes the bottom of the upper bottle with considerable force at each throw. The foun-

tain never requires readjusting; and to prepare it for a second period of activity, it is necessary only to invert the apparatus until water runs into the lower bottle, as shown in the illustration. It may be constructed of two Apparatuses, or, better, of two large bottles, one or two corks or rubber stoppers, and two jet-tubes, the bent one having a smaller opening than the other. The small funnel at the upper end of the straight tube is not a necessity, but it is easier to construct it thus (see "Auxiliary Work," p. 75) than to get the tubes accurately enough aligned to work well without.

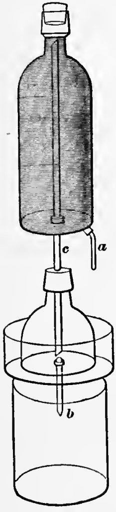


Aux. 25.

INFERENCES. 1. Explain the condition of the air in each bottle before action begins. 2. What force produces the first change in atmospheric conditions, and what is the change? 3. What other force comes into play, and what are its results, both visible and invisible? 4. Explain what occurs and why, when the apparatus is inverted.

Aux. 26. This is an intermittent fountain made of an ordinarily shaped quart bottle, the top of another used simply as a stand for the first, the bottom of a larger bottle, a glass fruit-jar, and pieces of tubing and corks. For greater stability, the apparatus-tube *c*, which is bevelled at both ends, should touch the dish at its lower, and the cork at its upper end. It need not be so long as shown in the cut; it would better be short enough to allow the bottle to rest upon its stand, into which it is firmly fitted with a cork. Tube *a* is the one that furnishes the intermittent stream, and if the apparatus be

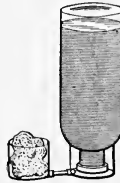
adjusted with care, another tube like it may be fitted to the opposite side of the bottle. Without *very* careful adjustment, however, air will enter one tube, and thus prevent an intermittent flow from either; hence you would better make the fountain with a single tube at first, then add the second if desired. A cap is placed upon this tube while the bottle is being filled and corked. Tube *b*, leading from the large dish to the jar below, furnishes a steady stream, and has a smaller opening than *a*; if small enough, the fountain will run for an hour or more, intermitting perhaps every other minute. If the holes in the bottles used must be drilled, have the one in this dish at or near the centre; but if you make them with files, the easiest way is to make the hole in this dish at the edge like the one for tube *a*, and make *b* with a double bend leading into the jar through a notch filed in the edge of its mouth. If large, stand may also need notching.



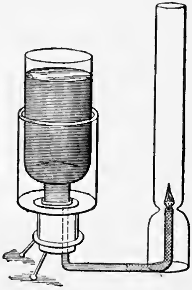
Aux. 26.

Aux. 27. This might be called a fountain sponge. The principle of its action is the same as that of the common fountain ink-well. The lower halves of two bottles are connected by a short piece of tubing. In one of the bottle-bottoms is placed the sponge; the other is placed like a cap over the mouth of a bottle filled with water, which is then inverted. The sponge keeps moist for

weeks or months, according to size of bottle and condition of the atmosphere. The water escapes only by evaporation from the sponge, if the latter is not removed from its dish. It may be used as a penwiper, or for moistening the gummed surfaces of stamps and envelopes.



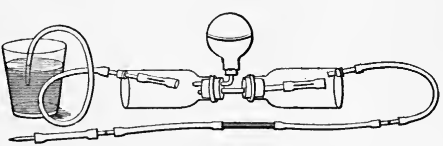
Aux. 27.



Aux. 28.

Aux. 28. This is a student-lamp, the operation of which is easily studied, as, with the exception of a cork and two nails, it is made entirely of glass. The cork tightly fits the inverted half bottle, and is perforated for a tube through which the oil reaches the wick. Two nails are driven into the cork, and, with the tube, form the support for the lamp. The chimney rests on the tube and two bits of wood, which are separated just enough to allow sufficient draft, the latter being easily adjusted by experiment. This piece, which is easily made, furnishes also a valuable auxiliary experiment in the study of combustion.

Aux. 29. This is an easily made and a very serviceable force-pump for use with either liquids or gases. With a single piece of rubber tubing in place of the long sectional one shown in the picture, it may be used for pumping air wherever in previous lessons the "atomizer bulb" is recommended. It works equally well in pumping or forcing a stream of water. The rubber bulb, which contains no valve, should be as heavy and elastic as possible. One end of a bent tube is fitted tightly into it by means of a piece of rubber tubing, the other end passes through a



Aux. 29.

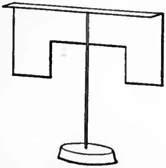
stopper containing two holes into one of the small bottles. The bottles are connected by a piece of glass tubing which has upon one end a valve like those in the apparatus for pumping water (Exp. 45). A similar valve is placed upon the end of the tube passing through the edge of the other bottle. The holes in the bottles may be drilled each in the centre of the bottom; if done with a file they are more easily made in the edges. Glass tubes are fastened in tightly with bits of rubber tubing. The glass tube with the valve on the end should be longer than the bottle. It is first inserted through the neck; then, if desired, it may be shortened. The long tube shown in the picture is made of rubber, glass tubes, and a short piece of rattan. The

glass tube in the outer end is a jet-tube; each of the other two has a small notch filed in it, and is of such size as to allow the rubber tube to slide over the notch to prevent leakage. The piece of rattan also has a small notch cut in it. A glass tube bent at a sharp angle, inserted in the end of a rubber tube and hung upon the edge of the tumbler, keeps in place better than rubber tubing.

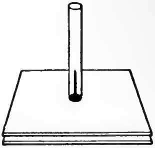
To study the operation of this pump, use it first with water, without the long delivery, having in its place a short rubber tube hanging in a dish to catch the water. With the hand, alternately compress and release the bulb; note what happens. By experiment find how to hold the pump to deliver a stream of water, and retain considerable air in each bottle; how to retain air in one bottle only; and how to fill both with water. Explain the working of the pump, naming each force in order, beginning with the force that compresses the bulb. Be particularly careful about the second and third forces, for very likely you will overlook one of them. Does the pump act differently with air than with water? Try each, and devise your own means for determining whether there is any difference in principle. The apparatus with delivery tube, shown in the picture, is used to illustrate the circulation of blood. The pump represents the heart; the tube, between the pump and the rattan, an artery; the rattan, the capillaries; the tube beyond, which should rest in the tumbler of water, represents a vein.

Every time you squeeze the bulb, the water spurting from the notch in the glass tube at the right of the rattan illustrates the manner in which one loses blood when an artery is severed. Slip the rubber tube over that hole

and work the pump; the slow but steady leaking from the rattan and the other glass notch illustrates how a wound bleeds when capillaries or a vein is cut. With the tube lying on the table while working the pump, press upon the tube, or bend it sharply beyond the rattan; the extra spurt of water from the jet-tube illustrates one way in which the circulation of blood is increased by exercise.



Aux. 30.



Aux. 31.

Aux. 30. Cut and bend a piece of heavy writing-paper or light cardboard as illustrated, and balance it on the point of a long needle. A large flat cork or any corked bottle makes a good stand for the needle. Fan one end with a piece of cardboard or with the hand, moving it from the centre outward, and the paper will swing towards the fan.

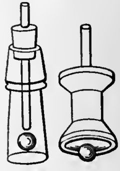
INFERENCE.

Aux. 31. Insert a glass tube tightly into a hole in a piece of thick cardboard. Insert a pin to its head in the centre of a piece of thin cardboard of about the same size. Place the former over the latter as illustrated; while blowing through the tube, lift it from the table, and the lower card will follow. In fact, you cannot blow it off.

INFERENCE.

Aux. 32. Much better than the wooden ball, in Exp. 79, is one of pith or of cork; but still better are the "oak-galls" or "oak-apples" which grow upon oak-leaves, as the result of the sting of a certain species of gall-fly. The oak-gall after becoming ripe has a hard shell, but is very light, and by a little skill can be kept in the air a considerable distance from the tube for nearly a minute. The best size is at least an inch in diameter. Of course a straight tube can be used by throwing the head back, and with skill the tube can be brought down till it is more nearly horizontal than perpendicular, and the oak-galls still kept revolving in mid-air. A quill toothpick, cut square at the outer end, makes a very serviceable tube for this and several other air experiments.

Aux. 33. Cut or break off the neck of a bottle (a smoothed edge is not essential), and fit it with cork and tube as illustrated. Hold it well down over one of the small wooden balls, and blow through the tube. The ball rises into the bottle-neck, and you cannot blow it out even with a powerful bellows. Use also a marble. A glass marble shows beautifully the rotations it makes. The same piece of apparatus may be made with a common spool by cutting out a cone-shaped cavity in one end, but a white glass bottle-neck makes a much prettier piece.



Aux. 33.

Inference. What lifts the ball against the strong current of air?

APPENDIX.

DIRECTIONS FOR MAKING AND ADJUSTING THE THREE CLASS PIECES OF APPARATUS.

THE barometer (EXP. 81) is very easily made and set up. The two glass tubes should be at least 33 and 5 inches in length, and better be about 36 and 10 inches, as then the instrument will give more accurate readings. The size of the tubes is not material, though of course the larger the bore, the more mercury required. We use tubing about $\frac{1}{4}$ inch in diameter, with a bore about one-third of that. The glass tubes are connected with a short piece of rubber tubing (about 3 inches).

The short tube, for greater ease in filling, should be funnelled, which is easily done by the aid of a Bunsen burner and pencil of charcoal. The long tube is closed at one end by holding it in the hottest part of the Bunsen burner blaze. (See Aux. Work.) To fill the barometer, insert a fine clean wire the entire length of the tubes. Slowly pour in the mercury, and the wire will enable the air to escape. Look occasionally, however; and if a small bubble of air is detected, churn with the wire until it rises to the surface of the mercury. Fill the long glass and the rubber tube, withdraw the wire, reverse the long tube, and put the barometer in its permanent place. We use one side of a window-casing, though it may be tacked to a narrow 4-foot piece of board, and hung wherever desired. The most convenient method of reading the barometer is by a sliding yard or metre stick, as shown in the cut. While this barometer will not be abso-

lutely accurate (but few are) on account of a small amount of confined air, it will answer all schoolroom purposes, better even than the more expensive ones. We keep our own make hanging beside one of the most expensive, but use our own almost invariably. In making and setting up a barometer, tubes and mercury should be clean and dry.

A very instructive barometer, which gradually changes to a "Boyle's Law" instrument, may be made with short pieces of tubing; and we earnestly recommend it as an auxiliary to Exp. 88. To make it, use, in place of the long tube, two pieces each 18 to 20 inches in length, and fasten the ends as closely together as possible with a piece of rubber tubing tightly tied or wired on. It is at first a good barometer, but the slow leaking in of air from day to day through the pores of the rubber makes an interesting series of experiments for the application of facts learned in Exp. 88. To test experimentally the correctness of the application, lay the "jointed" barometer flat on the table, when the enclosed air will be under normal pressure. Ask pupils to explain the difference in air pressure upon the outside of the rubber joint, and mercury pressure upon the inside.

The piece for Exp. 83 is very easily made of tubing of any convenient size. If of very small size, the wire is needed in filling, as with the barometer. If more than 13.6 inches of water is poured in, take it out with a capillary tube or with narrow strips of blotting-paper. Young pupils will not usually detect the slight variation from an inch in the mercury column made by a half-inch more or less of water, hence it is better to have it as exact as possible.

The apparatus for Exp. 88 (Boyle's Law piece) is as easily made as the barometer, but requires great care in the selection of tubes, and still greater care and skill in filling and setting up. It may be made with the upper end of the short glass tube closed like a barometer, or left open and provided

with a cap of rubber and glass as shown in the cut. The first method makes an instrument that is much more satisfactory to use, but somewhat difficult to fill. Select a 9.5-inch piece of tubing about .25 inch in diameter, taking special care that the bore is the same size throughout. Close one end in the Bunsen burner blaze, and by means of a short piece of rubber tubing, connect the other end with a small glass funnel, easily made of a piece of glass tubing. Select a glass tube nearly or quite twice as long as the first, with a bore the area of the cross-section of which is nearly twice that of the first tube, and funnel one end of it. Obtain a rubber tube with bore as nearly as possible the same as that of the short glass tube. The rubber tube should be firm enough not to stretch much, if any, under the weight of the mercury with which it is filled; hence the best quality of rubber is not the best for this purpose. Take a strip 39 inches in length, and force .5 inch of it over the small end of the long glass tube. If the rubber tube is not very thick-walled, it should be strengthened where it is stretched over the short glass tube. This is done by slipping over the end of it a one- or two-inch piece of larger rubber tubing before the glass tube is inserted. The rubber is stretched, and consequently weakened, more at the end of the long glass tube; but as it never has to bear a pressure of mercury much greater than outside air pressure, it does not need strengthening. To fill the short tube, use the wire as in the barometer, and pour in mercury till it measures exactly 6.5 inches deep after the wire is withdrawn, leaving 3 inches filled with air. Remove the funnel and rubber connector, and lay the tube upon the table. The mercury will not run out. Slip the end of the long rubber tube just barely over the end of a short piece of glass tubing, which then hang in a tumbler or small wide-mouthed bottle standing in a dinner-plate. Let the rubber tube lie upon the table with long glass tube at the other end, fastened in an upright or inclined position. Pour

in mercury till the rubber tube is full, and it is running out of the short tube. Be very sure that all air has been driven out of the rubber tube, then seize it between thumb and finger close to the short tube, and close it tightly; remove it from the tube, working over the plate to catch the mercury if any is spilled. Now comes the most difficult part of the work. The open end of the 9.5-inch tube must be inserted without getting in any more air, then the rubber tube is slipped on to cover just one-half inch of the glass tube. It probably will cost you several trials. It did me, and I do not yet always succeed the first time. The mercury is then shaken down, and the 3 inches of air got into the upper end of the tube. Fasten the rubber tube tightly to the short glass tube, by winding it with a piece of copper wire (about No. 18), which then fasten by twisting with pliers, and make a hook or loop of the ends with which to hang the tube. Now, holding both tubes perpendicular, raise the open tube till the mercury in it is 30 inches above that in the closed tube (if barometer stands at 30 inches), and the air in the closed tube occupies 1.5 inches. The mercury should show but a fraction of an inch in the long tube when held thus; when such is the case, the instrument is ready for adjusting to the wall or window-casing. One side of a window-casing makes a good place for it, as the rubber tubing filled with mercury can then lie upon the window-sill when the instrument is not in use. Drive the first nail or hook for the long tube so that it will hang just above the window-sill, and a nail for the short tube where it will hang with both mercury surfaces at the same level. If the wire loop for suspension is at the lower end of the short tube, instead of the upper end as shown in the cut, a hook, or two crossed nails, will be needed at a higher point to keep it in place.

Elevate the open tube until its mercury surface is 15 inches above that in the closed tube, and drive a nail on

which pupils will hang the tube when experimenting. Do the same for a difference of 30 inches. Return the tube to its first position, and drive nails for the short tube which will carry its mercury surface 7.5, 15, and 20 inches above the other.

The following is a better way to fasten the tubes where the window-sill does not project much beyond the casing, and where it is high enough from the floor so that there is room to lower the open tube till the mercury sinks in the short tube to the end of the rubber. Fasten as above, except with the tubes near the front edge of the casing, and with the short tube tacked firmly in place; then, instead of raising it, lower the open tube for the last three readings.

The above method of constructing and filling this apparatus is the best we have been able to devise; but, for fear some parties may find the task of filling too severe, we have devised an easier method. Leave the short tube open at the upper end, and fasten it to the rubber tube before filling. Make a cap by tightly wiring a half-inch piece of glass rod into one end of an inch piece of rubber tubing. With the short tube lacking about 3 inches of being full of mercury, crowd on this cap as tightly as possible, and wire it tightly, twisting the wire with pliers until it is nearly buried in the rubber. Then, if there is not exactly 3 inches of air when both mercury surfaces are at the same level, raise one tube or the other as may be necessary to allow air to be forced out or in through the rubber. While this method of construction has the advantage of being easy to fill, it has the disadvantage of leaking air through the pores of the rubber every time it is used, even if wiring is good enough to prevent its leaking between glass and rubber. Hence it requires constant attention to keep the correct amount of confined air. If, however, it is not left hanging long at either extreme of increased or

diminished pressure, it does not change volume of air very rapidly.

By either method of construction, this apparatus is by far the cheapest one yet devised for anything like the range it gives. Its cost, including mercury, should fall between one and two dollars, according to the size of tubes used and consequent amount of mercury required.

READING.

Badlam's Suggestive Lessons in Language and Reading. A manual for primary teachers. Plain and practical; being a transcript of work actually done in the school-room. $1.50.

Badlam's Stepping-Stones to Reading.— A Primer. Supplements the 283-page book above. Boards. 30 cts.

Badlam's First Reader. New and valuable word-building exercises, designed to follow the above. Boards. 35 cts.

Bass's Nature Stories for Young Readers: Plant Life. Intended to supplement the first and second reading-books. Boards. 30 cts.

Bass's Nature Stories for Young Readers: Animal Life. Gives lessons on animals and their habits. To follow second reader. Boards. 40 cts.

Firth's Stories of Old Greece. Contains 17 Greek myths adapted for reading in intermediate grades. Illustrated. Boards. 35 cts.

Fuller's Illustrated Primer. Presents the word-method in a very attractive form to the youngest readers. Boards. 30 cts.

Hall's How to Teach Reading. Treats the important question: what children should and should not read. Paper. 25 cts.

Miller's My Saturday Bird Class. Designed for use as a supplementary reader in lower grades or as a text-book of elementary ornithology. Boards. 30 cts.

Norton's Heart of Oak Books. This series is of material from the standard imaginative literature of the English language. It draws freely upon the treasury of favorite stories, poems, and songs with which every child should become familiar, and which have done most to stimulate the fancy and direct the sentiment of the best men and women of the English-speaking race. Book I, 100 pages, 25 cts.; Book II, 142 pages, 35 cts.; Book III, 265 pages, 45 cts.; Book IV, 303 pages, 55 cts.; Book V, 359 pages, 65 cts.; Book VI, 367 pages, 75 cts.

Penniman's School Poetry Book. Gives 73 of the best short poems in the English language. Boards. 35 cts.

Smith's Reading and Speaking. Familiar Talks to those who would speak well in public. 80 cts.

Spear's Leaves and Flowers. Designed for supplementary reading in lower grades or as a text-book of elementary botany. Boards. 30 cts.

Ventura's Mantegazza's Testa. A book to help boys toward a complete self-development. $1.00.

Wright's Nature Reader, No. I. Describes crabs, wasps, spiders, bees, and some univalve mollusks. Boards. 30 cts.

Wright's Nature Reader, No. II. Describes ants, flies, earth-worms, beetles, barnacles and star-fish. Boards. 40 cts.

Wright's Nature Reader, No. III. Has lessons in plant-life, grasshoppers, butterflies, and birds. Boards. 60 cts.

Wright's Nature Reader, No. IV. Has lessons in geology, astronomy, world-life, etc. Boards. 70 cts.

For advanced supplementary reading see our list of books in English Literature.

D. C. HEATH & CO., PUBLISHERS,

BOSTON. NEW YORK. CHICAGO.

SCIENCE.

Shaler's First Book in Geology. For high school, or highest class in grammar school. $1.10. Bound in boards for supplementary reader. 70 cts.

Ballard's World of Matter. A Guide to Mineralogy and Chemistry. $1.00.

Shepard's Inorganic Chemistry. Descriptive and Qualitative; experimental and inductive; leads the student to observe and think. For high schools and colleges. $1.25.

Shepard's Briefer Course in Chemistry; with Chapter on Organic Chemistry. Designed for schools giving a half year or less to the subject, and schools limited in laboratory facilities. 90 cts.

Shepard's Organic Chemistry. The portion on organic chemistry in Shepard's Briefer Course is bound in paper separately. Paper. 30 cts.

Shepard's Laboratory Note-Book. Blanks for experiments: tables for the reactions of metallic salts. Can be used with any chemistry. Boards. 40 cts.

Benton's Guide to General Chemistry. A manual for the laboratory. 40 cts.

Remsen's Organic Chemistry. An Introduction to the Study of the Compounds of Carbon. For students of the pure science, or its application to arts. $1.30.

Orndorff's Laboratory Manual. Containing directions for a course of experiments in Organic Chemistry, arranged to accompany Remsen's Chemistry. Boards. 40 cts.

Coit's Chemical Arithmetic. With a short system of Elementary Qualitative Analysis. For high schools and colleges. 60 cts.

Grabfield and Burns' Chemical Problems. For preparatory schools. 60 cts.

Chute's Practical Physics. A laboratory book for high schools and colleges studying physics experimentally. Gives free details for laboratory work. $1.25.

Colton's Practical Zoology. Gives a clear idea of the subject as a whole, by the careful study of a few typical animals. 90 cts.

Boyer's Laboratory Manual in Elementary Biology. A guide to the study of animals and plants, and is so constructed as to be of no help to the pupil unless he actually studies the specimens.

Clark's Methods in Microscopy. This book gives in detail descriptions of methods that will lead any careful worker to successful results in microscopic manipulation. $1.60.

Spalding's Introduction to Botany. Practical Exercises in the Study of Plants by the laboratory method. 90 cts.

Whiting's Physical Measurement. Intended for students in Civil, Mechanical and Electrical Engineering, Surveying, Astronomical Work, Chemical Analysis, Physical Investigation, and other branches in which accurate measurements are required.

I. Fifty measurements in Density, Heat, Light, and Sound. $1.30.
II. Fifty measurements in Sound, Dynamics, Magnetism, Electricity. $1.30.
III. Principles and Methods of Physical Measurement, Physical Laws and Principles, and Mathematical and Physical Tables. $1.30.
IV. Appendix for the use of Teachers, including examples of observation and reduction. Part IV is needed by students only when working without a teacher. $1.30.

Parts I–III, in one vol., $3.25. Parts I–IV, in one vol., $4.00.

Williams's Modern Petrography. An account of the application of the microscope to the study of geology. Paper. 25 cts.

For elementary works see our list of books in Elementary Science.

D. C. HEATH & CO., PUBLISHERS.

BOSTON. NEW YORK CHICAGO.

GEOGRAPHY AND MAPS.

Heath's Outline Map of the United States. Invaluable for marking territorial growth and for the graphic representation of all geographical and historical matter. Small (desk) size, 2 cents each; $1.50 per hundred. Intermediate size, 30 cents each. Large size, 50 cts.

Historical Outline Map of Europe. 12 x 18 inches, on bond paper, in black outline. 3 cents each; per hundred, $2.25.

Jackson's Astronomical Geography. Simple enough for grammar schools. Used for a brief course in high school. 40 cts.

Map of Ancient History. Outline for recording historical growth and statistics (14 x 17 in.), 3 cents each; per 100, $2.25.

Nichols' Topics in Geography. A guide for pupils' use from the primary through the eighth grade. 65 cts.

Picturesque Geography. 12 lithograph plates, 15 x 20 inches, and pamphlet describing their use. Per set, $3.00; mounted, $5.00.

Progressive Outline Maps: United States, *World on Mercator's Projection (12 x 20 in.); North America, South America, Europe, *Central and Western Europe, Africa, Asia, Australia, *British Isles, *England, *Greece, *Italy, New England, Middle Atlantic States, Southern States, Southern States—western section, Central Eastern States, Central Western States, Pacific States, New York, Ohio, The Great Lakes, Washington (State), *Palestine (each 10 x 12 in.). For the graphic representation by the pupil of geography, geology, history, meteorology, economics, and statistics of all kinds. 2 cents each; per hundred, $1.50.

Those marked with Star (*) are also printed in black outline for use in teaching history.

Redway's Manual of Geography. I. Hints to Teachers; II. Modern Facts and Ancient Fancies. 65 cts.

Redway's Reproduction of Geographical Forms. I. Sand and Clay-Modelling; II. Map Drawing and Projection. Paper. 30 cts.

Roney's Student's Outline Map of England. For use in English History and Literature, to be filled in by pupils. 5 cts.

Trotter's Lessons in the New Geography. Treats geography from the human point of view. Adapted for use as a text-book or as a reader. $1.00

D. C. HEATH & CO., PUBLISHERS,

BOSTON. NEW YORK. CHICAGO.